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This study of current and prospective pest control strategies focuses on the problems involving commercial corn and soybean production for feed purposes. It examines current pest control practices, direct and indirect benefits and costs, and future implications of the current trends in pest control. A broad look at future prospects assumes considerable importance of corn and soybeans in view of world food shortages and shifts in U.S. farm policy.

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An Assessment of Present and Alternative Technologies

VOLUME II

Corn/Soybeans Pest Control

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PEST CONTROL:
An Assessment of Present and Alternative Technologies

VOLUME II

Corn/Soybeans Pest Control

The Report of the Corn/Soybeans Study Team
Study on Problems of Pest Control
Environmental Studies Board
National Research Council

NATIONAL ACADEMY OF SCIENCES
Washington, D.C. 1975

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This is Volume II of *Pest Control: An Assessment of Present and Alternative Technologies*. The other volumes are:

Volume I	*Contemporary Pest Control Practices and Prospects: The Report of the Executive Committee*
Volume III	*Cotton Pest Control*
Volume IV	*Forest Pest Control*
Volume V	*Pest Control and Public Health*

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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PREFACE

This study originated in discussions in the Executive Offices of the National Academy of Sciences in March 1971. The Environmental Studies Board (ESB) subsequently continued the discussions and appointed a Planning Committee to develop a detailed proposal. The Planning Committee, sponsored by funds from the Scaife Family Charitable Trusts, submitted its report to the ESB in April 1972. The ESB approved the report and appointed Dr. Donald Kennedy of Stanford University as Chairman of the Executive Committee of the "Study on Problems of Pest Control: A Technology Assessment." Financial support for the study was secured from the U.S. Department of Agriculture, the U.S. Environmental Protection Agency, and the Ford Foundation. We thank these public and private agencies for their assistance.

The Executive Committee's charge was to assess the diverse effects on society resulting from efforts to control pests and to evaluate long-range alternatives for accomplishing pest control. The charge also explicitly called for an examination of social and institutional factors important in pest control practices, factors that must be considered in any recommendations for changes in pest control policy. The Planning Committee recommended and the Executive Committee agreed that the most effective way to examine these problems would be through a series of case studies. Four such studies were selected. Three of them centered on specific agroecosystems: cotton, corn and soybeans, and timber. The fourth dealt with issues related to the control of pests of public health significance in the United States and abroad. Each case study examined the pest species involved, current control measures, and the benefits and costs of controlling the pests by various techniques.

The Corn/Soybeans Study Team members, whose names and affiliations are listed on page iii, developed this report and the recommendations contained in it between September 1973 and April 1975. Team members were selected so that a variety of technical expertise in the agricultural, biological, and social sciences would be included. The charge to the study team from the Environmental Studies Board, as well as the scope and organization of this report, are summarized in Chapter 1. It should be mentioned here, however, that because of constraints of time and other resources no new research was undertaken for the purposes of this study. Hence, this report is a multidisciplinary synthesis and compilation of information that is already known but widely scattered in the literature of several professional disciplines.

The reports of the Executive Committee and the study teams are all available from the National Academy of Sciences in five volumes under the general title *Pest Control: An Assessment of Present and Alternative Technologies*. Volume One comprises the report of the Executive Committee and all the summaries and recommendations of the four study team reports. The report of the Executive Committee, in addition to drawing on the findings of the individual study teams, covers other areas not specific to those teams. The remaining four volumes are bound separately as follows: Volume Two, *Corn/Soybeans Pest Control;* Volume Three, *Cotton Pest Control;* Volume Four, *Forest Pest Control;* and Volume Five, *Pest Control and Public Health.*

ACKNOWLEDGMENTS

Many people and organizations assisted this study team in its work. Several should be singled out for special thanks.

Howard Engstrom, of the National Research Council staff, attended all meetings of the study team, assisted in arrangements, and participated in the preparation of the final report. Dr. John Perkins served as Principal Staff Officer for the study as a whole, and Bette Lou Fields took over his responsibilities in the final phases of the study. Linda Jones, Lucette Comer, Mary Dong, Susan Lesser, Christina Neumann, and Estelle Miller provided able and tireless secretarial support. We are grateful for their generous and effective contributions. In addition, Mr. A. Dan Tarlock, of the Cotton Study Team, met with us and was informative on many legal aspects of pest control.

We are grateful to Dr. Rosemarie von Rumker of RvR Associates for access to that firm's unpublished study of corn and soybean pest control in Illinois and Iowa. The material in their report was most helpful. Our thanks are extended to Dr. G. C. Klingman, Director of Plant Science Field Research, Eli Lilly and Company. He and his colleagues cordially hosted the study team on a tour of the firm's research laboratories at Greenfield, Indiana, and discussed issues of mutual interest with us. We also thank the Federal Reserve Bank of Minneapolis for offering their facilities for one of the team's regular meetings.

Finally, we appreciate the efforts of the secretarial staff of the Department of Agricultural and Applied Economics at the University of Minnesota, where several versions of this report were typed. In particular, we acknowledge the diligent work of Mary Strait, Twila Olson, and Lucia Miklas.

Naturally, none of the people and organizations mentioned here are accountable for the material contained in this report.

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CONCLUSIONS AND RECOMMENDATIONS

The corn and soybean sector is, in many ways, the backbone of U.S. agriculture. Sensibly protecting this sector from pest problems, while minimizing environmental, economic, and social problems, is a major challenge today and in the years ahead.

It is not difficult for members of a study team such as this to spin out dozens of recommendations for public and private action. These recommendations can be general or quite specific. They can be in conflict with each other or internally consistent depending upon the composition of the group and the specificity involved. Additional research usually can be strongly recommended on a variety of questions. However, the following general conclusions, recommendations, suggestions, and ideas are distilled as the most important from the many points discussed and debated among the team members. Full agreement was not always achieved on each of these points, and some issues are not as fully developed here as individual team members might have wished.

The study team is fully agreed, however, that pest problems and pest control strategies in the corn/soybean sector of U.S. agriculture are in a continual state of evolution and development. At this time, the immediate pest problems generally can be controlled with present methods, which emphasize herbicides, insecticides, and plant breeding for disease resistance. Yet in some cases, especially with soil insecticides, these methods are only partially effective and questionable from the environmental point of view. Consequently, this is no time for complacency and lack of concern. Unexpected insect and plant disease problems can explode at any time with disastrous results. The 1970 corn leaf blight episode provides a glimpse of the potential consequences of a major pest outbreak. Continuing sophistication in cropping methods and the changing weed population requires improved weed control and more attention to actual and potential chemical carryover problems. Current and developing externalities (side effects) involving the target pest species, the environment, and rural society suggest the need for continued improvements in corn/soybean pest control.

On-farm pest control of weeds and insects by current, mainly chemical, methods is generally a highly profitable activity at current and probable future price and production relationships. Successful pest control typically increases output and reduces costs because (1) it permits higher average yields, and (2) it allows farmers to handle more land with the same or less labor. Because of this tendency, the substantial benefits of corn and soybean pest control are distributed widely through the economy in the form of lower product prices and larger supplies than otherwise would occur. The main benefits flow ultimately to buyers of meat, livestock products, and edible oils. Foreign buyers and food-aid recipients of U.S. farm products benefit because of lower prices and more abundant supplies than otherwise would be available. Similarly, the U.S. balance of payments is favorably affected through increased foreign exchange earnings. Pest control failures have essentially opposite results. These costs are registered mainly as higher prices and shorter supplies in the food sector.

Although the substantial benefits of modern pest control are relatively clear and direct, the persistent costs to society from corn and soybean pest control occur mainly as unmeasured externalities. These effects ripple through the environment and through time in complex and subtle ways.

On balance, successful pest control in corn and soybeans has been a vital link in the emergence of the United States as the world's lowest-cost, most-efficient, and most-reliable producer of these commodities. It should remain a high-priority item on the nation's agricultural policy agenda.

An early objective of the team was to identify possible new strategies for pest control in corn and soybeans. We feel that we have succeeded in describing some ways by which to encourage public action and research that will lead to new strategies. But we have not identified any radically different approaches ready for widescale adoption. In the near-term future greatest opportunities for improvement lie in: (1) greater reliance on pest management systems; (2) use of pesticides geared to real needs rather than insurance or prophylactic treatments;

(3) rigid adherence to the correct timing, rates, and methods of application to avoid spillover/drift and undesirable residues; (4) minimal use of persistent chemicals; and (5) better-trained applicators.

If current economic trends continue, no major policy and regulatory changes occur, and the trajectory of technological change remains steady, the study team foresees the following evolution occurring in pest control methods over the next 10-15 years.

1. Application methods and timing will continue to change but primary reliance on chemicals will remain for insect and weed control.
2. More selective, less-persistent insecticides will be available, and they will be applied by better-trained applicators.
3. Continued sophistication will occur in corn and soybean herbicides, but expanding applications are likely as total acreage increases and as mechanical tillage operations are reduced.
4. Breeding and selection for disease and insect resistance will continue as major components of the sector's pest control activity.

The assessment of current trends and their implications is not an endorsement of them. Knowledge about future developments is imperfect, yet the study team generally agrees that current methods of pest control in corn and soybeans to date have resulted in no known major environmental hazard over wide areas. Possible adverse future effects of continued use of chlorinated hydrocarbons are not fully known, but the Environmental Protection Agency recently has banned the agricultural use of aldrin and dieldrin and is considering a ban on chlordane and heptachlor. Environmental residues of these banned chemicals, therefore, will not increase in the corn/soybean sector.

Since many important pests of corn and soybeans are unpredictable in nature with regard to both time and place of population buildup and damage, a major policy priority should be to develop good predictive capabilities.

This study team, therefore, recommends that an increased public commitment be made to monitor pest populations in the field and to develop effective surveillance systems for detecting potential pest buildups, new pests, and new races of current pests.

With more effective prediction, pest control by any means can be improved. In particular, the need for routine chemical treatments can be reduced throughout the corn/soybean sector. A major research effort is needed to identify the biological, physical, and environmental factors that bear on reliable prediction techniques. Currently a substantial portion of the insecticide used in corn involves insurance or prophylactic applications by growers. The sporadic nature of infestations, relatively low price of insecticides, and the indirect nature of potential costs and consequences associated with such treatments lie behind this phenomenon. While private efforts to monitor and predict major pest problems may be helpful to individual growers and regions, such efforts probably will not be sufficient.

This study team also recommends that in addition to improved pest monitoring and prediction, the feasibility of broadened crop insurance schemes be studied, with pest insurance as an important feature. Such insurance written by public or private agencies would help achieve economic security for individual growers and thereby reduce insurance applications of chemicals. It is important to prevent prophylactic chemical applications on soybeans from becoming as widespread as they are now on corn.

It is important that pest control efforts involving corn and soybeans move further toward preventing problems rather than curing them once they have emerged. In general, we will likely be most successful if we learn to live with and attempt to "manage" most corn and soybean pest species in a rational way.

The study team therefore recommends that research and especially action programs be directed toward pest "management," broadly defined. In the corn/soybean sector, management is the key to effective and profitable pest control over the long run. Containment and suppression of well-established insects, weeds, and plant diseases at or below their economic thresholds, appropriately calculated, should be the major objective of management systems. The complex interactions of living communities make these activities very difficult, but they also make the complete eradication of well-established pests generally unworkable with present technology. However, for exotic pests in an early development stage or with new discoveries in pest control, eradication may become an appropriate management goal.

Agricultural ecosystems are "unnatural" in a biological sense. Yet, they are complex communities of plants and animals, including pest species. In dealing with pest species, the more natural and self-generating a control system is, the more likely it is to be effective and environmentally safe in the long run. Such naturalness can be fostered through biological and agricultural research. Some research activities of this kind, however, which may seem to be low-return or high-risk endeavors, are not funded when budgets are tight.

Consequently, the study team recommends that biome or ecosystem studies of the kind traditionally conducted in natural or undisturbed environments also be conducted in the disturbed or manipulated agroecosystems where corn and soybeans are produced together and constitute the major crops. The most effective principles and techniques developed and identified through previous studies, including multistate Integrated Pest Management Research Programs, should be applied to the corn and soybean sector.

Extensive base information is needed on all biological entities and their interactions in the system. Such knowledge can help in the development of alternative pest control technologies and reduce future environmental hazards. However, this knowledge must be synthesized in useful ways.

Therefore, the study team recommends that the techniques of systems analysis and modeling be applied more intensively and specifically to the evaluation of production and pest control methods in the corn and soybean sector. We encourage the development of interdisciplinary and interagency teams to achieve balance in the direction of such studies. These studies should define the interaction of production practices, pest control technologies, economics, and potential public benefits and costs. These studies might encourage a series of monographs funded through appropriate public and private agencies.

Nonchemical pest control in the corn/soybean sector is lagging behind that in other commodity sectors, such as cotton. Part of the reason for this is that it is difficult now to pinpoint major systematic environmental problems specifically associated with pest control in corn and soybeans. Although the corn/soybean sector is only one part of the total agricultural system, chemical pest control in it represents a sizeable portion of the total pesticide load introduced by man into the agricultural environment. The ability of the environment to absorb an ever-increasing load, including that from the corn/soybean sector, remains an important and worrisome unknown.

The study team recommends that research efforts be expanded in the area of alternative biological methods and strategies for pest control. These efforts combined with suggested improvements in the prediction and targeting phases of current pest management methods will help to control and possibly reduce the total pesticide load on the environment, make judicious use of the chemicals that are applied, and offset specific problems that are present. The latter include target species resistance; spillover/drift; and the buildup of unwanted residues in soil, water, and some foods.

Biological and social scientists from the nonagricultural disciplines and from nonagricultural institutions should be heavily involved in this work. The institutional and administrative barriers to professional cooperation and public funding of such research across disciplinary lines should be reduced.

The development of today's pest control technology has been largely the result of the long-standing and closely-knit interrelationship of the land grant system, the federal government, private industry, and farmers. Private universities and nonagricultural public universities traditionally have not been directly involved in agricultural pest control research and evaluation. This has occurred for a variety of historical and professional reasons. Greater interaction between the two systems as recommended above would help to avoid a more narrow and possibly shorter-range view of pest problems and control strategies than might otherwise occur.

In the corn/soybean sector, nonchemical methods other than genetic resistance are being recommended mainly for insect and plant disease control as part of mixed control strategies. At the moment, these methods mainly involve crop rotation and crop sanitation practices. More sophisticated biological methods of control probably will not involve readily marketable products or services. Consequently, publicly-funded development and implementation likely will be required. Private industry cannot be expected to provide the needed research and distribution functions. Moreover, implementation of alternative nonchemical strategies may require major changes in the traditional separation between public and private decision making. More public involvement, responsibility, and perhaps control would be needed for success of these methods.

Much of the pest control effort in the corn/soybean sector involves plant breeding for genetic resistance to disease and the extensive use of herbicides. Neither of these has generated prolonged or acute environmental problems to date. The continuing evolution of insect control technology also provides little direct evidence of acute environmental damage within the sector, although some problems have been identified. These problems mainly involve increasing resistance of some target insect species, especially corn rootworm, and the presence of soil and food residues of the persistent chemicals aldrin and dieldrin. Additional direct costs and externalities of corn and soybean pest control are caused by spillover/drift, accidental use of incorrect materials, and improper disposal of leftover chemicals.

Consequently, this study team supports the concept of increased training in the use and application of pesticides and increased public control of pesticide use as exemplified in the Federal Insecticide Fungicide and Rodenticide Act as amended in 1972 by the Federal Environmental Pesticide Control Act.

Important provisions of this 1972 Act (1) permit the classification of pesticides into general and restricted use and (2) require the certification of applicators using restricted pesticides.

In addition, the study team recommends that more and better information and educational opportunities be made available to policymakers and the general public concerning pesticide use and regulations. The study team anticipates some additional employment in or shifts of employment to rural areas stemming from these new pesticide regulations. This may be an advantage and worthy of further study.

Modern pest control is part of a technological revolution that has greatly increased farm production and yet has fostered a massive reduction in farm numbers and farm people. Many social problems in both rural and urban United States can be traced to this phenomenon.

This study team recommends that when new legislation, regulation, or public support for pest control activities are considered, specific attention should be directed to *their potential employment and locational effects on rural people and rural society. Such effects may be very difficult to measure or evaluate, but the effort should be made.*

It is possible that in the future serious unexpected outbreaks of insects or disease may threaten the corn/soybean sector. Currently available technology may be unable to control such outbreaks if their sources are exotic and unresearched. It is even possible that today's pest control methods may contribute, in unknown ways, to them. The capacity for such "back-up" response at present is fragmented and incomplete.

This study team, therefore, recommends that strategies for back-up systems of pest control in the corn/soybean sector be developed. This includes (1) public and private attention to building inventories of chemicals that differ from those in common use, (2) legal and administrative procedures to move quickly against pest outbreaks with currently restricted products if necessary, and (3) comprehensive and diverse inventories of plant genetic materials from which new resistance can be developed as quickly as possible.

Representing the public's interest in pest control will continue to be the responsibility of agencies such as the U.S. Department of Agriculture, the Environmental Protection Agency, and the Land Grant University System. The agricultural extension service of the land grant system has an especially important role to play. The extension service deals directly with farmers, rural people, and their organizations in an educational and advisory capacity. The ability of extension workers to respond objectively to questions and issues concerning pest control and environmental protection is more crucial now than ever before. This challenge emerges in an atmosphere of increasing public concern about the environment and about the impact of agricultural change on society as a whole. This concern has generated new legislation and regulations. It has also introduced strains upon the traditional fabric of relationships between the land grant complex, farmers, agribusiness, and the general population.

The study team recognizes that the close relationship between the agricultural chemical industry and the public agricultural establishment has been criticized, sometimes justly and sometimes unfairly. For the most part, this relationship is based upon mutual respect and responsible collaboration. Active cooperation in this field has been important in the development of many safe and effective methods of pesticide use.

In order to insure that the public's interest is protected as pest control methods continue to evolve, the study team recommends that the independence and objectivity of all publicly-supported agricultural workers who deal with pest control issues be guarded and strengthened. Although this will involve continued evaluation of the traditional ties between private industry and the public agricultural establishment, the many long-standing positive relationships between the two sectors should be sustained.

Effective and ecologically sound pest management in the corn/soybean sector for today and tomorrow depends upon (1) the development of basic knowledge, (2) the translation of this knowledge into dependable technologies and practices, (3) the implementation of these technologies and practices at the production level, and (4) the continuing evaluation of their biological, economic, and social implications. Such pest management is a complex and difficult process.

1

INTRODUCTION

Since the late 1930s, agricultural productivity in the United States has swept upwards at an almost unbelievable pace. Through the practical application of mechanical innovations, biological discoveries, and abundant fertilizers, farm output has more than doubled since 1935 with virtually no change in the farmland base. The details of this drama form a familiar story that need not be repeated here. Yet the means for achieving these productivity advances, so crucial to the modernization and technical development of U.S. agriculture, generate anxiety among some laymen and scientists. This uneasiness comes as we attempt to gain a broad perspective about the quality and balance of life in our nation and food needs both here and around the world.

Part of the increased productivity experienced in this country during the past 30 to 40 years hinges on the control of various pests that compete with man for the agricultural harvest. Modern control of most insects, weeds, plant and animal diseases, rodents, and other pests has been achieved with chemical agents and through the development of disease- and insect-resistant varieties and strains. Our reliance on these two general methods, especially the first, causes much of society's uneasiness about pest control in agriculture.

The possibility of unexpected and diverse effects of agricultural chemicals on man and his environment today and tomorrow is a principal concern of some observers. In addition, selection criteria for crop and livestock breeding for pest resistance may result, among other things, in less diversity and increased vulnerability of commercial production to unexpected natural phenomena that the more naturally occurring varieties can withstand. It is to the general topic of pest control in agriculture that this report is directed. The specific focus in this case study

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is upon current and prospective pest control strategies in the important corn/soybean sector of U.S. agriculture.

This report is the outcome of joint deliberations and individual study by a multidisciplinary team of nine professional workers in the natural and social sciences most closely associated with pest problems in agriculture. The team functioned as part of the Study on Problems of Pest Control under the auspices and with the assistance of the Environmental Studies Board of the National Academy of Sciences.

OBJECTIVES AND SCOPE OF THE REPORT

The charge to the study team identified four major objectives to which the activities of the team and the preparation of this case study report were directed. The first was to identify the main pest problems in the corn/soybean sector of the U.S. agricultural production plant. The second was to provide a summary and analysis of the current pest control methods being employed in the sector and their implications for society, both rural and urban, and the environment. Third, plausible new directions and alternatives in pest control and pest management were to be discussed and analyzed to the extent now feasible. The final major objective was to provide an overall assessment of the pest control situation and to advance recommendations for dealing with immediate and potential problems.

The makeup of the study team permitted a blend of several viewpoints in each phase of the inquiry. These viewpoints encompass the scientific and technical core of knowledge about pest control, relevant economic considerations, ecological issues, and related social and institutional aspects. This study was not designed as a benefit/cost analysis in the technical or strictly quantitative sense; such calculations were not possible on a broad basis. It was, instead, intended to be a rather general interpretive evaluation of the current and potential pest control situation in the corn/soybean sector. Although no new research activities were undertaken, attention was given to research activities that are needed in this field. Questions about how current research resources for dealing with pest control are allocated and distributed were also covered.

In tackling this project, a number of somewhat arbitrary decisions were made to confine its scope to manageable proportions. The corn/soybean sector of U.S. agriculture was given a geographic definition in order to delimit the relevant production and pest control questions. Thus the focal point was the traditional Corn Belt, where corn and soybeans are produced in close association with each other. The region of primary concern included all of Illinois, Indiana, and Iowa. In addition, western Ohio, southern and west-central Minnesota, northern and west-central Missouri, and eastern Nebraska also were considered. Figures 1-1 and 1-2 show that this is the main region of overlapping corn and soybean production. Moreover, this region also exhibits roughly similar environmental, economic, and institutional characteristics related to farming.

The major emphasis of the report is on pest control problems involving commercial corn and soybean production for grain purposes. But because of some special characteristics of production and handling, the pest control problems of seed corn and seed soybeans also are singled out for specific attention. Where relevant, pest problems peculiar to corn silage and sweet corn are mentioned. In addition, some discussion and analysis of pest control problems in the postharvest storage and handling of corn and soybeans is presented.

Designating the pests to be considered was also somewhat arbitrary. Generally speaking, pests are organisms that diminish the value of resources in which man is interested. They may interfere with the growth of crops or livestock; they may adversely affect man's health; or they may reduce the quality of part of man's environment. For some purposes, pests are defined as all organisms that man considers detrimental in some way, except those that are directly pathogenic to humans. For this particular study, the pest group is confined to insects, weeds, and causal agents of plant disease (i.e., fungi, bacteria, viruses, nematodes, and mycoplasmas). Omitted are pests such as rodents, birds, and other wildlife that may reduce corn and soybean production.

ORGANIZATION OF THE REPORT

An overall assessment and several recommendations by the study team are set forth at the beginning of the report.

Following the Introduction in Chapter 1, Chapter 2 deals with the corn/soybean sector in U.S. agriculture and with the main pest problems faced in the sector. It discusses the special pest problems in the seed corn and seed soybean industry; current pest control practices in the corn/soybean complex; benefits as well as costs, direct and

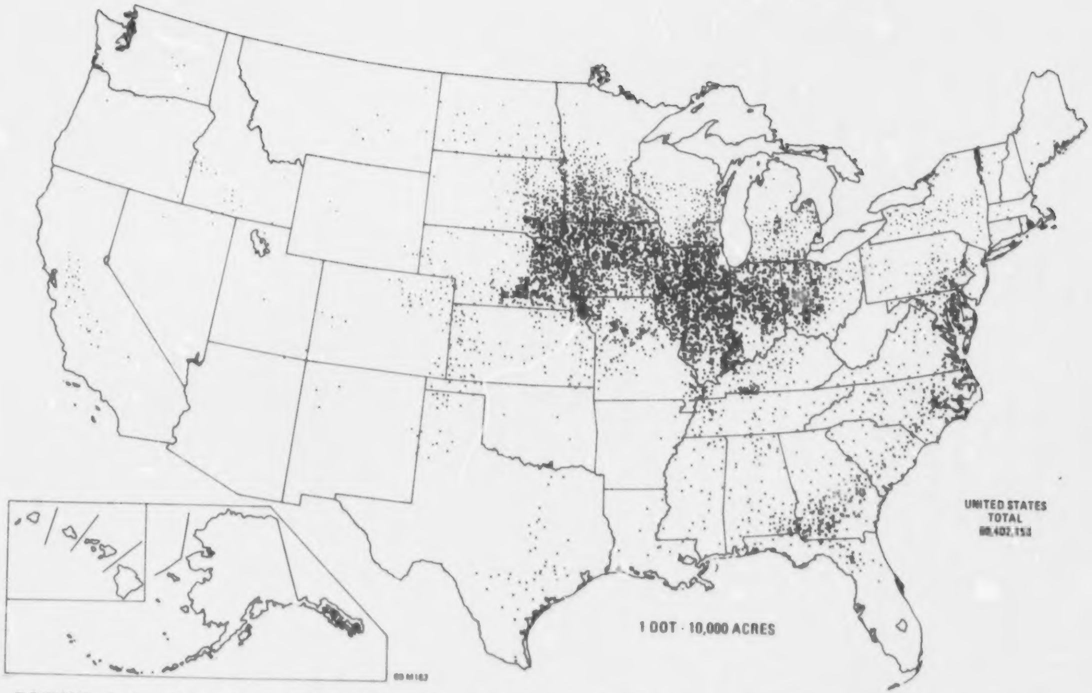
UNITED STATES
TOTAL
66,402,153
1 DOT - 10,000 ACRES

FIGURE 1-1 Corn harvested for all purposes, 1969. From Department of Commerce, Social and Economic Statistics Administration, Bureau of the Census.

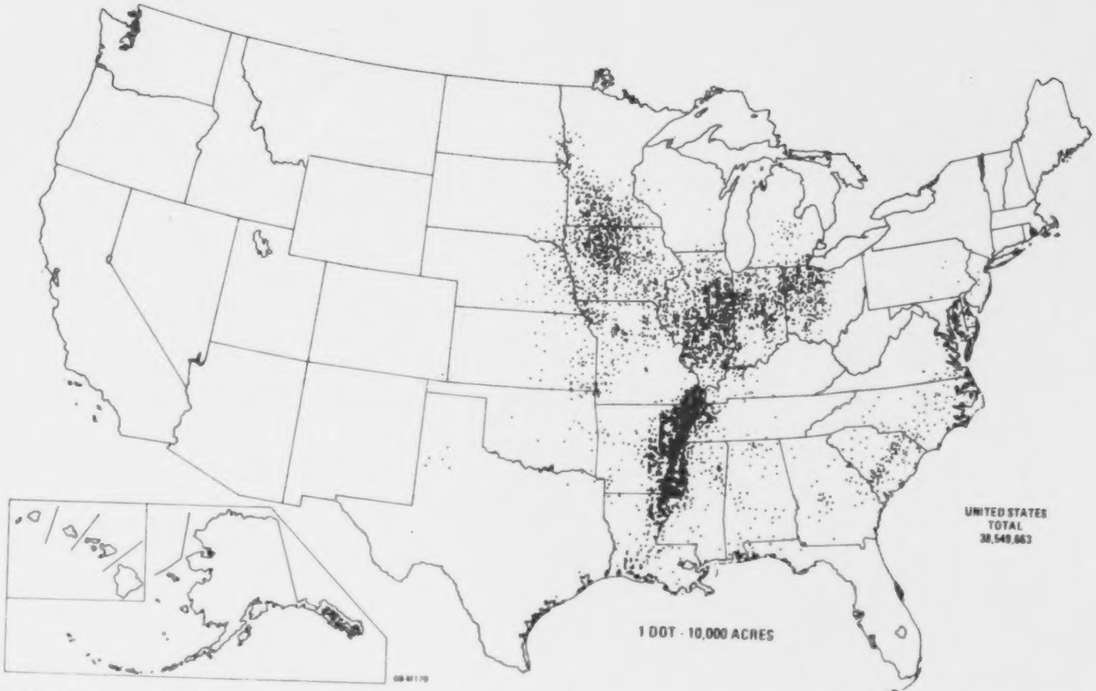
UNITED STATES
TOTAL
38,548,663
1 DOT · 10,000 ACRES

FIGURE 1-2 Soybeans harvested for beans, 1969. From Department of Commerce, Social and Economic Statistics Administration, Bureau of the Census.

indirect; and the future implications of the current trends in pest control.

Chapter 3 is concerned with new directions in pest control for the corn/soybean sector, including feasible or nearly-feasible alternatives and some very new or novel ideas and concepts that may have practical relevance in the future. In view of recent upheavals and shortages in world food markets, coupled with the abrupt shift in U.S. farm policy embodied in the Agricultural Act of 1973, a broad look at future prospects becomes especially important.

Chapter 4 treats current and future pest control methods and how they are influenced by the activities and links among research agencies and other public and private establishments.

2

THE CORN AND SOYBEANS SECTOR IN U.S. AGRICULTURE

CORN AND SOYBEANS IN THE CORN BELT

The location of the corn-soybean economy in the Midwest is the result of complex ecological forces, management factors, and the availability of supporting services, including transportation to domestic and foreign markets.

The two crops have similar, though not identical, requirements for water, temperature, soil pH, phosphorus, potassium, and micronutrients. Although corn and soybeans differ in day-length responsiveness, the most significant cultural difference between the two crops is the nitrogen needed for corn. Fortunately, the geographic areas involved are small. Nitrogen fertilizer, which is produced heavily in Louisiana, Mississippi, and Texas because of the availability of natural gas, is easily barged up the Mississippi, Illinois, and Ohio Rivers or moved through pipelines into the Corn Belt.

Both crops, traditionally grown in rows to facilitate cultivation for weed control (and corn for ear-corn harvesting), require land that is not subject to severe erosion. However, this constraint can be overcome to a considerable extent by strip cropping, contour farming, and more recently by reduced- or zero-tillage using dependable herbicides.

The Corn Belt soils are relatively easily tilled and are generally free of stone. Wind blown or lake bed soil deposits of medium texture are predominant. Topography and soil texture are suitable for large-scale machinery.

The equipment needed for seedbed preparation, planting, weed control (rotary hoe, cultivator, herbicide sprayer), harvesting, and storing corn and soybeans are virtually the same. Growing only these two crops minimizes the variety of farm equipment needed and thus favors investment in large-scale units.

All of the soybeans and a substantial part of the corn grain moves into commercial grain channels. Similar equipment can handle, store, and transport corn and soybeans. Extensive facilities have been developed in the Corn Belt to handle the two grains for both domestic and international markets. Both move into foreign markets in large volumes. Ready accessibility to the St. Lawrence Seaway, the barge system on the Ohio-Illinois-Mississippi Rivers, and relatively short rail hauls to New Orleans provide an economic advantage for corn and soybean production in the Corn Belt over many other regions.

Although the boundaries are determined partly by proximity to markets and links with the livestock economy, the areas of intensive corn and soybean cropping in the Corn Belt are limited, on the north by heat units available for growth, on the west by the effective moisture supply, and on the south and east by topography suitable for row crops.

The northern boundary line for grain corn is set at about 120 frost-free days and 15 heat units per day (degrees above 55 F). This is punctured by fingers of producing areas on sandy and gravelly soils that are favorable for extra-early planting. The boundary for corn for silage is roughly 150 to 200 miles north of that for grain corn. Elevation, because of its effect on temperature, and proximity to large bodies of water, which delays fall frost, are of local importance in determining the feasibility of production near the northern limit for corn.

The western boundary is governed by a combination of growing-season rainfall, water-supplying power of the soil, and relative humidity. The limit for corn, in the absence of irrigation, is about 38 cm (15 in.) (in the period April to September) in South Dakota and 53 cm (21 in.) in Kansas and Oklahoma.

The southern and eastern boundaries for both corn and soybeans are determined more by the suitability of topography for intensive row-crop production than by climatic factors. Both crops are grown intensively south of the main Corn Belt on nonerosive floodplain soils.

The planting and harvesting seasons for the two crops overlap somewhat, but except for unusual weather conditions do not directly conflict in the Corn Belt.

Narrow Crop and Genetic Base

The corn-soybean region is characterized by: (1) a high proportion of the acreage in harvested crops (Figure 2-1), (2) lack of crop diversity, and (3) a narrow germ plasm

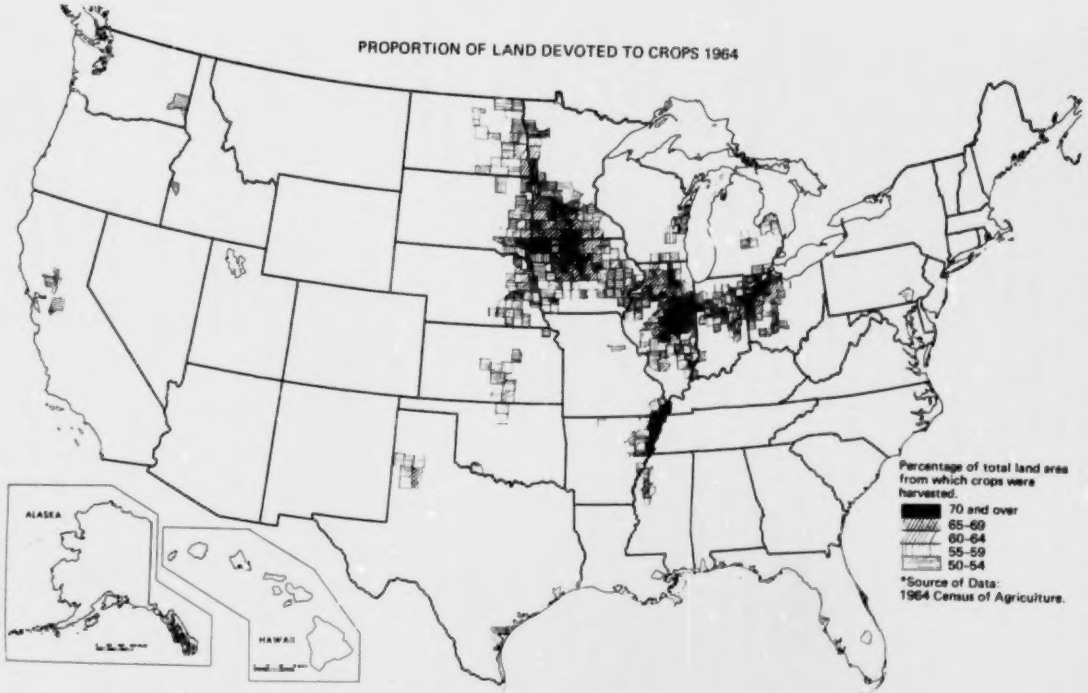
PROPORTION OF LAND DEVOTED TO CROPS 1964
ALASKA
HAWAII
Percentage of total land area from which crops were harvested.
70 and over
65-69
60-64
55-59
50-54
*Source of Data:
1964 Census of Agriculture.

FIGURE 2-1 Counties with 50 percent or more of land area in harvested crops.

base within both crops. Total harvested cropland in the United States in 1973 was about 325 million acres, of which about 20 percent was corn and 14 percent soybeans. Though corn and soybeans are grown intensively, the acreage on which either crop occurs for more than three consecutive years is very small. Fully continuous corn or soybeans are essentially nonexistent.

Most corn hybrids in the Corn Belt reflect inbred lines developed from a Reid varietal background crossed with inbreds from a Lancaster background. At any time, relatively few inbred lines are used extensively. For example, the National Academy of Sciences (1972) reported (from a survey by the American Seed Trade Association) that the proportion of total usage of the five most extensively used public inbred lines in the parentage of commercial hybrids increased from 18.3 percent in 1956 to 39.6 percent by 1964, and was 66.4 percent in 1970. Different inbred lines were involved in each survey year. Based upon the reasonable assumption that private inbred lines developed by commercial companies have a genetic background similar to public lines, it is clear that the genetic base for more than 60 million acres has become increasingly narrow.

The soybean germ plasm base is even narrower than with corn. In recent years, 20 varieties occupied 92 percent of the acreage in 12 northern states. However, the parentage of all varieties traces to only 10 ancestral types. In 12 northern states and adjacent areas of Canada, Mandarin parentage appears in 98 percent of the acreage, Richland in 57 percent, Manchu (via Lincoln) in 54 percent, Illini in 48 percent, Mukden in 42 percent, and CNS in 37 percent. Not only do varieties grown on most of the present acreage trace to only six introductions from Manchuria, but the six are similar in type and are likely somewhat related. After the corn blight episode in 1970, which resulted from a uniform cytoplasm base, soybean breeders examined the cytoplasm parentage and found that, among varieties grown in the 12 northern states and adjacent regions of Canada, 72 percent of the acreage had Mandarin cytoplasm and most of the remainder represented Illini or Mukden cytoplasm.

Genetic vulnerability to hazards because of a narrow genetic base has been thoroughly evaluated elsewhere. There are benefits associated with uniformity. Plant breeders and seedsmen examine a wide range of germ plasm in their research and testing programs. Only those varieties or hybrids that are superior are released to farmers. These may be few in number because only the best are put into production. This germ plasm is best able to exploit the soils and environment in the sector with high yields. These benefits occur each year. To hedge against hazards, some people have proposed the need for more genetic diversity. Some plant breeders conclude that introductions of new and exotic germ plasm should be in small doses so that highly desirable characteristics of present widely used varieties will be maintained.* Others suggest a more extensive system of germ plasm material in diverse geographic areas of the world to improve screening for disease resistance.† Yet, they do not support the concept that a greater number of varieties should be grown commercially solely for the sake of diversity.

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*"The conclusion from all this is that we have rather narrow germplasm base represented in our commercial varieties. Not only are the introduced parental lines few in number but they are mostly rather similar types and presumably themselves are somewhat related. This raises the questions, 'How did we get that way?' and 'What do we do about it?'

"When you look over experiment station records on soybean breeding the past 50 years you see large numbers of diverse parental varieties used compared with the narrow germplasm of the successful lines developed. The conclusion seems evident that crosses involving the basic six Manchurian varieties are either the only ones which can produce competitive commercial varieties or at least provide for better genetic populations in which to select. The present narrow germplasm base exists not because these were the only crosses that breeders looked at but because these were the successful ones. Most of us who have tried to select from populations involving exotic germplasm will agree that it's not easy to come up with a successful commercial variety using such material" (Bernard 1972).

†"In addition to the germplasm reserve of introduced material, we also maintain many of our breeding lines that have been evaluated but have not merited being released for production. Many of these are good agronomic types with multiple disease resistance. Should a new problem arise, it seems to me that it is better to have these lines in reserve for testing than to merely increase the number of varieties in production in an attempt to have diversity. Should one of these lines demonstrate resistance to a new production hazard, it could be increased and put into production very rapidly" (Hartwig 1972).

With the exception of corn blight in 1970 (which occurred because of cytoplasmic susceptibility), lack of genetic diversity probably has not caused special pest problems in corn or soybeans, nor has it lead to unusual applications of pesticides. However, the concentration of more than 85 percent of harvested acres in Illinois in only two crops, corn and soybeans, has resulted in the persistence and perhaps increase in some insect, weed, and disease problems.

Corn Pests

Weed Problems

Without control, weed infestations in the Corn Belt would cause disastrous yield reductions in corn. The high proportion of annual row crops, such as corn and soybeans (up to 85 percent in some areas), gives annual weeds an excellent opportunity to germinate and become established. Preparing the seedbed for corn and soybeans also gratuitously prepares a seedbed for weed seeds. Some annuals and several perennials start early and thrive when the soil is too wet and temperature too cold for corn. The source of the weed infestations is the massive reservoir of seeds and vegetative reproductive organs in the soil. Numbers of viable weed seeds vary considerably, but the minimum rarely falls below several million per acre and an excess of 100 million per acre has been reported. When buried in the soil, substantial numbers of weed seeds may remain alive but dormant for a half century or more. If brought near the surface, these seeds readily germinate, grow, and produce seed to replenish the soil reservoir. Asexual vegetative reproduction from organs in the soil play a similar role in the perpetuation of weed infestations. Tubers, bulbs, and buds located on rhizomes, roots, or stolons serve as a means of vegetative reproduction. Vegetative reproductive organs also can be counted in millions per acre and will persist for many years in a dormant state when buried in the soil.

Corn yield losses from weeds arise from competition for the limited supplies of water, nutrients, and light. Losses vary greatly, but in some Illinois experiments they averaged 81 percent in unweeded plots. In the same experiments, reductions varied from 28 to 100 percent. In similar studies for three years at four locations in Minnesota, corn yields were 51 percent less than that of weeded plots, with the reductions ranging from 16 to 93 percent (Behrens and Lee 1966).

Specific weed problems in corn in the Corn Belt are listed in Table 2-1. The grouped foxtail species (green, yellow, and giant) are considered the worst weed problem in corn in all seven Corn Belt states. Foxtails are almost universally present. Giant foxtail and some strains of green foxtail are moderately tolerant of atrazine, the most widely used corn herbicide. However, recent substantial increases in usage of several highly effective grassy weed herbicides (alachlor, propachlor, butylate) should result in better control and thus reduce the future importance of these species. Shattercane, fall panicum, and

TABLE 2-1. Weed Species[a] Considered in a 1973 Corn Belt Survey to be a Major Weed Problem in Corn

Common Name	Scientific Name
Foxtail sp. (giant, green, yellow)	*Setaria* sp. (*S. faberi, S. viridis, S. glauca*)
Pigweed sp.	*Amaranthus* sp. (*A. retroflexus, A. hybridus*)
Velvetleaf[b]	*Abutilon theophrasti*
Panicum sp.[b]	*Panicum* sp. (*P. dichotomoflorum, P. capillare*)
Shattercane[b]	*Sorghum bicolor*
Yellow nutsedge	*Cyperus esculentus*
Canada thistle	*Cirsium arvense*
Quackgrass	*Agropyron repens*
Johnson grass	*Sorghum halpense*
Common lamb's-quarters	*Chenopodium album*
Smartweed sp.	*Polygonium* sp. (*P. pensylvanicum, P. persicaria*)
Common cocklebur	*Xanthium pensylvanicum*
Barnyard grass	*Echinochloa crusgalli*
Crabgrass sp.	*Digitaria* sp. (*D. ischaemum, D. sanguinalis*)
Common sunflower[b]	*Helianthus annuus*
Common milkweed[b]	*Asclepias syriaca*
Field bindweed	*Convolvulus arvensis*
Honeyvine milkweed	*Ampelamus albidus*
Morning glory sp.	*Ipomoea* sp. (*I. purpurea, I. hederacea*)

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[a] Listed in descending order of importance.
[b] Increasing in severity.

crabgrass have increased in importance because they are tolerant to atrazine, but the new grass herbicides mentioned above should reverse this trend. Barnyard grass is susceptible to atrazine and has declined in relative importance in recent years.

Among annual broadleafs, the pigweeds have retained their listing as the most troublesome species in spite of their susceptibility to most of the major herbicides. They are prolific seed producers, and their seeds remain viable in the soil for many years. Because of only fair control with present herbicides, velvetleaf (throughout the Corn Belt) and common sunflower (in the western Corn Belt) have increased in prominence in recent years. Atrazine is very effective on sunflower, but usage is low in the western Corn Belt. Common cocklebur and common lamb's-quarters populations have changed little in relative importance in recent years, and control in corn is easily accomplished. Smartweed species have declined in importance. Climbing milkweed and the morning glories are limited to the southern parts of the Corn Belt and are increasing slightly because atrazine gives only partial control.

Among perennials, yellow nutsedge has increased in importance until recently because of tolerance to all available herbicides. Quackgrass remains a serious problem in the northern Corn Belt in spite of susceptibility to atrazine. Rotations that include oats and hay aggravate the problem.

Canada thistle is the most troublesome perennial broadleaf weed in corn production, especially in the northern Corn Belt. There is some evidence that tolerance of Canada thistle to 2,4-D has increased after 25 years of usage, but this herbicide still gives adequate control of Canada thistle in corn. It is not clear that this increased tolerance is actually due to increased genetic resistance.

The effects of cropping sequence, cultivation, and herbicides on the mass of weed growth and abundance of weed seeds were studied over a 6-year period by Slife (1973a). Cropping systems included monocultures of corn, soybeans and wheat, corn-corn-soybeans, and corn-soybeans-wheat. Herbicide treatments were grouped into three categories: (1) none, (2) a different herbicide each year, and (3) the same herbicide for 6 years in broadcast and band placement.
From this research it is clear that:

- Monoculture combined with continuous use of one herbicide leads to a buildup of certain weed problems.

- A corn-soybean sequence using different herbicides effectively suppresses weeds.
- Introducing a small grain brings new weed problems into a corn-soybean system.

The high concentration of corn-soybeans in the Corn Belt has unquestionably resulted in a greater application of herbicides in the region than would have prevailed under a more diversified cropping system. This is because alternative crops such as oats do not require or receive nearly so much herbicides as row crops.

Insect Pests

There are more than 30 species of insects that attack corn in the sector. The occurrence and the level of the pest population varies from area to area and season to season. Thus, the loss attributed to any particular species varies widely by year and by location. Virtually all of these 30 insect species have the potential of attaining injurious levels. Several different schemes have been used to categorize the insect pests of corn, including area of plant attacked (aboveground vs. belowground), type of injury caused (sucking vs. chewing), and multiple vs. single generation. The following categorization has been adopted for this report: (1) primary pests, both consistent and sporadic, and (2) secondary pests (see Table 2-2).

A primary consistent insect pest is defined as a species that is consistently present and causing damage. Problems are directly related to the absolute level of the pest population through the sector. Primary constant pests of corn include the European corn borer [*Ostrinia nubilalis* (Hübner)], western [*Diabrotica virgifera* (LeConte)] and northern [*D. longicornis* (Say)] corn rootworm, and the corn leaf aphid [*Rhopalosiphum maidis* (Fitch)].

The European corn borer is an important insect pest throughout the Corn Belt. Climatic factors, disease, and parasite incidence greatly influence population level, and subsequent damage. The average annual loss from 1968 through 1971, based on the Cooperative Economic Insect Report, was reported to be in excess of 200 million bushels for the sector. At present market value, this represents a loss of more than half a billion dollars in corn production. The average annual loss during the past 10 years has displayed a fivefold variation among years. The lowest reported annual loss in the past 5 years, in 1972, was

9 percent of the total yield, with a range in state losses from 3.4 percent to 16.9 percent. This loss estimate is based on a survey conducted by state and federal scientists. Surveys have been conducted in a systematic fashion for this insect for several decades. Thus, of all the corn pests, the most complete information on distribution, abundance, and biology is on this species. Throughout the major portion of the corn sector, there are two generations per year. In the spring, moths lay eggs on the tallest corn plants in the area. The emerging larvae feed primarily in the whorl. The more mature larvae bore into the stalk in late June and early July. One borer per plant will cause about a 3 percent loss in yield. Adults from the first generation emerge during August and lay eggs. Initially the larvae feed in the leaf sheath, silk, kernels, and pollen. Subsequently, they burrow into the stalk and ear shank, thus causing major losses from stalk and shank breakage.

The western and northern corn rootworms are also primary pests of corn. The northern rootworm is distributed throughout the Corn Belt. Presently, the primary western rootworm distribution includes Colorado, on the west; Minnesota and Michigan, on the north; Indiana, on the east; and Kansas, on the south. Its life and seasonal cycle are shown in Figure 2-2. Resistance by this pest population to chlorinated hydrocarbons was observed in 1959 in south-central Nebraska, following exposure to this group of chemicals for less than 10 years. Figure 2-3 shows the distribution of resistant western corn rootworms from 1960 to 1963. Currently, the species is resistant to chlorinated hydrocarbons throughout its entire range. Concurrent with the development of this resistance to chlorinated hydrocarbons, the distribution has extended eastward. The estimated advance infestation is 50 to 150 miles per year. This advancing front represents a primary and unanticipated problem. Prior to the development of resistance, the western rootworm was a relatively lesser pest found primarily in Nebraska and western Iowa. It may soon become distributed all across the eastern Corn Belt.

Although the northern corn rootworm is a primary pest, it is of lesser consequence than the western species. It is a mixed species in its resistance to the chlorinated hydrocarbons. Resistance is confined to specific locales. Losses due to rootworm result from root feeding by larvae and silk feeding by adults. Environmental conditions markedly affect losses. Moisture stress and root injury have a compounding effect. With abundant moisture and wind, root-injured plants lodge relatively easily. This

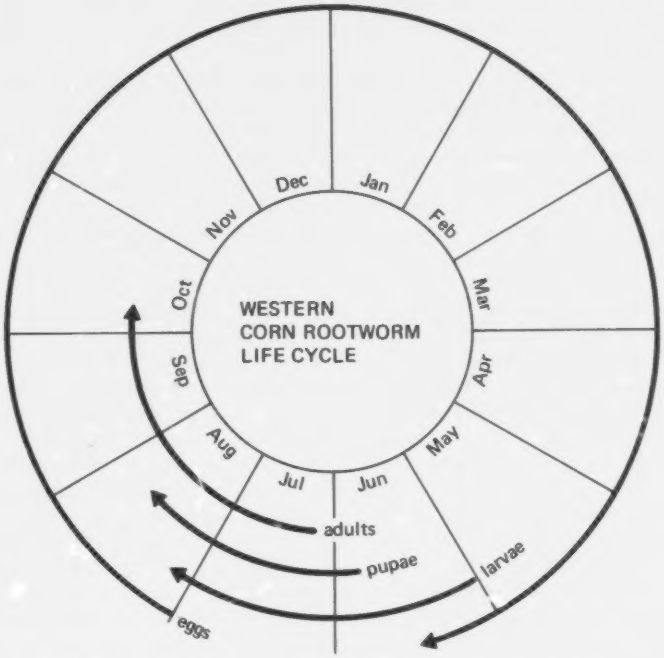
WESTERN
CORN ROOTWORM
LIFE CYCLE
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
adults
pupae
larvae
eggs

FIGURE 2-2 Life cycle of western corn rootworm.

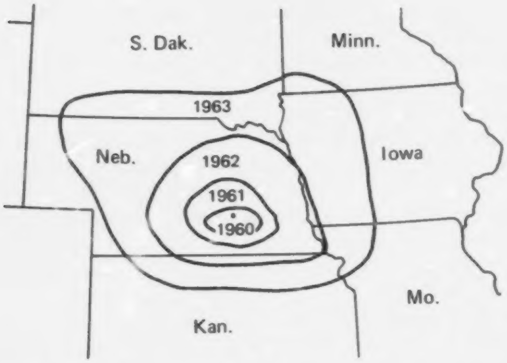
S. Dak.
Minn.
1963
Neb.
1962
Iowa
1961
1960
Mo.
Kan.

FIGURE 2-3 Distribution of resistant western corn rootworm, beginning in 1960.

causes considerable harvesting difficulty and loss. Rootworms are a primary problem where corn is planted following corn.

The corn leaf aphid is universally distributed throughout the corn-growing area. This insect causes direct loss and is important as a vector of virus diseases. It has become more important with the transition from double-cross to single-cross hybrids. The pest may develop in such numbers as to interfere with pollination. Consequently, an increasing number of problems are reported by hybrid seed producers.

Sporadic primary pests are those species that are highly destructive but variable in both time and place of occurrence. Serious outbreaks occur in an area but may not necessarily recur in the same area annually. Insects included in this category are cutworms, wireworms, and grubs. In each case there is a complex of species involved (see Table 2-2). The larvae of these species feed primarily at or below ground level and have commonly been termed the "corn soil insect complex." Species of this group are distributed throughout the Corn Belt. These pests may be highly destructive in local areas. They represent a primary control problem, because the damaging stage lives in the soil and its occurrence is sporadic. This "complex" is more likely to cause damage when a grass or sod field is followed by corn. Black cutworm problems are most likely to occur in river bottomland or land that is subject to flooding.

Secondary pests differ from primary pests in that they are either less destructive when present or, if highly destructive, have a limited distribution. This group includes grasshoppers, leafhoppers, thrips, mites, flea beetles, seed-corn maggots, seed-corn beetles, corn earworms, billbugs, armyworms, stalk borers, southwestern corn borers, and western bean cutworms. Several of these insects, including leafhoppers and flea beetles, are primary vectors of plant diseases. The destructive potential of some of these diseases such as Stewarts wilt and maize dwarf mosaic has been rated as severe to very severe. Seed corn beetle problems have been reported with increasing frequency over the past 5 years. Apparently this is due to the development of resistance to the chlorinated hydrocarbon insecticides.

The western bean cutworm traditionally was a primary pest of field beans in Nebraska. In the mid-1960s it began to infest corn and has since spread to several hundred thousand acres. The damage caused is similar to that of the corn earworm, because the larvae feed in the ear.

TABLE 2-2 Insect Species Considered To Be a Problem in the Corn Sector

Classification	Common Name	Scientific Name
Primary consistent pests	European corn borer	*Ostrinia nubilalis* (Hübner)
	Western corn rootworm	*Diabrotica virgifera* (LeConte)
	Northern corn rootworm	*D. longicornis* (Say)
	Corn leaf aphid	*Rhopalosiphum maidis* (Fitch)
Primary sporadic pests	Black cutworm	*Agrotis ipsilon* (Hufnagel)
	Wireworm	*Elateridae* sp.
	Cutworm	*Noctuidae* sp.
	Grubs	*Phyllophaga* sp.
Secondary pests	Corn earworm	*Heliothus zea* (Boddie)
	Stalk borer	*Papaipema nebris* (Guenée)
	Grasshoppers	*Melanoplus* sp.
	Slender seed-corn beetle	*Clivina impressifrons* (LeConte)
	Seed-corn beetle	*Agondoerus lecontei* (Chaudoir)
	Seed-corn maggot	*Hylemya platura* (Meigen)
	Grape colaspis	*Colaspis brunea* (Fabricius)
	Southern corn rootworm	*D. undecimpunctata howardi* (Barber)
	Billbug	*Calendra maidis* (Chitt)
	Southwestern corn borer	*Diatraea grandiosella* (Dyar)
	Armyworm	*Pseudaletia unipuncta* (Haworth)
	Flea beetle	*Chaetocnema pulicaria* (Melsheimer)
	Thrip	*Limothrips cearealium* (Halid)
	Western bean cutworm	*Loxagrotis albicosta* (Smith)
	Mite	
	Slug	

However with the western bean cutworm several larvae may be found per ear in infested plants. This is a possibly serious pest that has changed host, and its potential for spread is now largely unknown. This is an example of an unexpected problem in which there was a change in host by an endemic species.

The development of agronomic practices, such as modified tillage, has resulted in some of the pests becoming of greater importance. This has been the situation for wireworms, cutworms, armyworms, and mites. Generally, minimum tillage has complicated the application of conventional insecticide treatments.

An estimate of the potential corn losses as a result of pests is given in Table 2-3. The tabular entries are based on some limited loss-estimate data and the collective judgment of several scientists in the sector. Only a limited number of pest species are present in economic populations at any time in a particular area. Though some species are judged to be of minimal economic importance across the entire sector, they are frequently highly destructive and their economic impact is quite marked in specific areas. Potential losses exceed actual losses because of relatively successful control measures. However, there are a number of notable examples of both control failure and species adaptation in recent years (western corn rootworm and western bean cutworm). These examples serve as immediate reminders that insects have the potential of causing severe losses when environmental conditions are favorable and controls are not practiced. Potential losses within specific local areas may range up to 50 percent if controls are not applied.

Disease Problems

Corn is subject to at least 50 diseases. Many are endemic in the Corn Belt, and several occur every year with varying degrees of severity. A few are capable of developing in epidemic proportions some years and causing severe losses in yield. Others have never caused appreciable losses except in localized areas. Several exotic diseases are known but have not yet spread into the sector.

Most corn diseases (Table 2-4) are caused by fungi, bacteria, viruses, mycoplasma, and nematodes. The causal agent can be transmitted from diseased to healthy plants.

Root and stalk rot diseases are present on corn every year. They are related to plant stresses that, in turn, are associated with the intensive crop production. Yield

TABLE 2-3 An Estimate of the Present and Potential Importance of Insect Pests on Corn

Insect	Losses with Present Controls		Losses if Present Controls Not Used	
	Special Local Areas	Cornbelt	Special Local Areas	Cornbelt
European corn borer	M	L	H	M
Western corn rootworm	M	L	VH	M
Northern corn rootworm	M	L	H	M
Southern corn rootworm	VL	VL	L	VL
Black cutworm	M	L	H	L
Wireworm	M	VL	M	L
White grub	L	VL	M	L
Grape colaspis	VL	VL	VL	VL
Seed-corn maggot	L	VL	M	VL
Seed-corn beetle	L	VL	M	VL
Armyworm	L	VL	M	VL
Fall armyworm	L	VL	M	VL
Corn leaf aphid	L	L	M	L
Billbug	L	VL	M	VL
Stalk borer	M	VL	M	L
Flea beetle	L	L	M	L
Corn earworm	L	L	L	L
Southwestern corn borer	M	VL	M	VL
Mite	M	VL	H	VL

VL = Very Low (0-1%)
L = Low (2-10%)
M = Moderate (11-35%)
H = High (36-50%)
VH = Very High (over 51%)

NOTE: These estimates are based upon empirical data where available and, otherwise, on the general knowledge and judgment of several scientists in the field.

TABLE 2-4 Corn Diseases Present in the Sector, Their Present Importance, and Their Potential Importance in Causing Crop Losses

Disease	Causal agent	Losses with Present Controls in Effect		Potential Losses Should Present Controls Fail or Not Be Used	
		Local Areas	In Sector	Local Areas	In Sector
Seed rot	*Pythium* sp.	L	L	H	M
Seedling blight	Various fungi	L	L	M	M
Stewarts bacterial wilt and leaf blight	*Erwinia stewartii*	M	L	H	L
Northern leaf blight	*Helminthosporium turcicum*	H	L	VH	H
Southern leaf blight	*H. maydis*	M	L	VH	M
Helminthosporium leaf spot	*H. carbonum*	M	VL	M	L
Yellow leaf blight	*Phyllosticta maydis*	M	L	H	L
Eyespot	*Kabatiella zeae*	L	VL	L	VL
Crazy top	*Sclerophthora macrospora*	VL	VL	VL	VL
Sorghum downy mildew	*Sclerospora sorghi*	L	VL	H	L
Common corn rust	*Puccinia sorghi*	M	L	M	M
Southern corn rust	*P. polyspora*	VL	VL	VL	VL
Other leaf blights	Various bacteria and fungi	L	VL	L	VL
Maize dwarf mosaic	MDM virus	M	VL	VH	L
Maize chlorotic dwarf	MCD virus	M	VL	H	L
Bacterial stalk rot	*Erwinia* and *Pseudomonas* sp.	VL	VL	VL	VL
Pythium stalk	*Pythium aphanidermatum*	VL	VL	VL	VL
Diplodia stalk rot	*Diplodia maydis*	M	L	M	M
Gibberella stalk rot	*Gibberella zeae*	M	L	M	M
Fusarium stalk rot	*Fusarium moniliforme*	L	VL	L	L
Charcoal rot	*Macrophomina phaseoli*	L	VL	L	L
Common smut	*Ustilago maydis*	L	VL	H	M
Nematodes	Various species	VL	VL	VL	VL
Storage rot	*Aspergillus* and *penicillium* sp.	M	L	VH	M

VL = Very Low (0-1%) L = Low (2-10%) M = Medium (11-35%)
H = High (36-50%) VH = Very High (over 51%)

NOTE: These estimates are based upon empirical data where available, and otherwise on the general knowledge and judgment of several scientists in the field.

losses for the Corn Belt, estimated to be 10-14 percent, are substantial but not catastrophic. However, the diseases are difficult to bring under adequate control.

Helminthosporium leaf blights sometimes develop in epidemic proportions. The much publicized southern corn leaf blight epidemic *(Helminthosporium maydis)* of 1970 destroyed about 25 percent of the crop in the Corn Belt and 15 percent nationwide. Yield losses in states further south were twice as great. Northern leaf blight *(Helminthosporium turcicum)* can cause up to 50 percent yield losses in some parts of the Corn Belt. Helminthosporium leaf blight diseases are influenced by several factors, weather conditions being the most important. In dry seasons they often cause no economic losses. These diseases can be adequately controlled by genetic manipulation.

New diseases occur periodically because of (1) natural evolutionary changes that take place in the causal agents of plant disease; (2) changes in corn hybrids grown; and (3) changes in cultural practices used on farms. For the same reasons, currently known diseases will increase in importance some years and decrease in others.

Present control measures for corn diseases are relatively successful (Table 2-4). However, when environmental conditions are unusually favorable for disease or when available control practices are not used or fail, then diseases can cause severe losses. Fortunately, few diseases are important in a given year and these only within localized areas (the 1970 blight being a notable exception). Furthermore, not all hybrids are equally susceptible to each disease. Though losses of 25-50 percent are possible some seasons, history suggests that losses of such magnitude would not occur in a sequence of more than two or three years. A complete crop failure due to disease throughout the whole geographic area is remote indeed.

Insects, Fungi, and Other Pests Affecting Grain Quality in Transit and Storage

At least 25 species of *Pencillium, Aspergillus, Trichoderma, Fusarium,* and other fungi can invade and cause rots in moist grain being stored or in transit. Below 12 percent moisture or 35 F (2 C), mold growth is not a problem, but infection that occurred in the field prior to harvest already may have reduced grain quality.

Moldy grain has a reduced feeding value. But, more importantly, it may be toxic to animals. Several *Fusarium* species, for example, produce compounds toxic to certain classes of livestock. Swine refuse to eat *Fusarium*-infected grain. If swine are hungry enough to consume infected grain, an emetic factor induces vomiting. Zearaleonone is an estrogenic factor and causes abortion or an abnormal development of female sexual organs.

Some toxins produced by fungi in moldy corn grain are injurious to man as well as to many other mammals. *Fusarium tricinctum* produces a toxin that has caused human deaths. Even more important are the several aflatoxin compounds produced by *Aspergillus flavus*. They are one of the most potent of the known carcinogens. The Food and Drug Administration's (FDA) tolerance for aflatoxin in corn to be processed for food is 10 ppb (parts per billion) and for livestock feed, 20 ppb. Fortunately aflatoxin is not a major problem in corn and soybeans and especially not in the Corn Belt.

Insects living in stored grain accelerate mold damage, especially near the lower moisture limit for mold growth. Rodents (rats and mice) damage, consume, and contaminate corn in storage. This is of special importance in corn used for human food, and the FDA has established tolerances for evidences of rodent contamination.

Soybean Pests

Weed Problems

As with corn, weed control in soybeans is essential to success. In 17 trials involving 5 years and 7 locations in Minnesota and Nebraska, soybean yields in weedy plots averaged 45 percent less than in weed-free plots (Behrens 1959-1963, Burnside 1970-1972). Losses ranged from 0 to 100 percent. With cultivation only, yields averaged 19 percent less than in weed-free plots. By proper use of herbicides with cultivation, yield losses can be greatly reduced.

Because large, green weeds interfere more with soybean than corn harvesting, there is an additional incentive for effective weed control. A few farmers still hand-hoe their soybean fields. Others walk through the fields when the crop is nearly full size to remove large, late-developing weeds.

Volunteer corn is very troublesome in some soybean fields every year. Dinitroaniline herbicides are capable of controlling or suppressing corn growth, but they are not always used. The problems of volunteer corn are not always anticipated soon enough for proper control measures to be applied.

The relative importance of two competitive factors, nutrients and light, is quite different for soybeans than for corn. The symbiotic relationship of soybeans with nitrogen-fixing bacteria provides the soybeans with nitrogen. This reduces the importance of nitrogen competition with weeds compared to its importance in corn production. But light competition is of greater importance, because soybeans are much shorter and are often overtopped by weeds.

Specific weed problems in soybeans are listed in Table 2-5. Many of the most troublesome species--foxtail, pigweed, and velvet leaf--are common to both corn and soybeans. Jimsonweed deserves special mention because of complaints of contamination of overseas shipments of soybeans by its poisonous seeds.

Soybean Insect Pests

The soybean plant is subject to attack by insects that cause a reduction in quantity and quality of the yield. Insects feed on both the pods and the foliage. Soybeans in certain growth stages can tolerate considerable foliar feeding by insects with minimal yield loss. However, defoliation during and after bloom contributes to yield loss. More than one species of foliar feeder may be present on the crop during the season. As soybeans are planted on increased acreages and introduced into new areas, new insect problems continually emerge.

The insect pests of soybeans have been categorized as follows:

PRIMARY PESTS:
- Mexican bean beetle, *Epilachna varivestis* (Mulsant)
- Green stink bug, *Acrosternum hilare* (Say)
- Bean leaf beetle, *Cerotoma trifurcata* (Foster)

SECONDARY PESTS:
- Major
  - Green cloverworm, *Plathypena scabra* (Fabricius)
  - Wireworm, *Limonius dubitans* (LeConte); probably *Melanotus* sp.
- Minor
  - Thistle caterpillar, *Vanessa cardui* (Linnaeus)
  - Japanese beetle, *Popillia japonica* (Newman)
  - Garden webworm, *Lexestege similalis* (Guenée)
  - Differential grasshopper, *Melanoplus differentialis* (Thomas)
  - Redlegged grasshopper, *Melanoplus femurrubrum* (DeGreer)

TABLE 2-5 Weed Species[a] Considered in a 1973 Corn Belt Survey to be a Major Problem in Soybeans

Common Name	Scientific Name
Foxtail sp.	*Setaria* sp. (*S. faberi*, *S. viridis*, *S. glauca*)
Pigweed sp.	*Amaranthus* sp. (*A. retroflexus*, *A. hybridus*)
Velvetleaf[b]	*Abutilon theophrasti*
Common cocklebur	*Xanthium pensylvanicum*
Smartweed sp.	*Polygonium* sp. (*P. pensylvanicum*, *P. persicaria*)
Morning glory sp.	*Ipomoea* sp. (*I. purpurea*, *I. hederacea*)
Common ragweed	*Ambrosia artemisiifolia* L.
Yellow nutsedge[b]	*Cyperus esculentus*
Jimsonweed[b]	*Datura stramonium* L.
Quackgrass	*Agropyron repens*
Canada thistle	*Circium arvense*
Johnson grass	*Sorghum halpense*
Common sunflower[b]	*Helianthus annus*
Panicum sp.[b]	*Panicum* sp. (*P. dichotomiflorum*, *P. capillare*)
Corn, volunteer	*Zea mays*
Wild mustard	*Brassica kaber*
Shattercane[b]	*Sorghum bicolor*
Crabgrass sp.	*Digitaria* sp. (*D. ischaemum*, *D. sanguinalis*)
Giant ragweed[b]	*Ambrosia trifida* L.
Field bindweed	*Convolvulus arvensis*
Common milkweed[b]	*Asclepias syriaca*
Prickly sida	*Sida spinosa* L.
Goose grass	*Eleusine indica* L.
Black nightshade[b]	*Solanum nigrum* L.
Venice mallow[b]	*Hibiscus trionum* L.
Hemp dogbane[b]	*Apocynum cannabinum* L.

[a] Listed in descending order of importance.
[b] Increasing in severity.

Corn earworm, *Heliothis zea* (Boddie)
Blister beetle complex
Twospotted spider mite, *Tetranycus urticae* (Koch)
Fall armyworm, *Spodoptera frugiperda* (J. E. Smith)
Tarnished plant bug, *Lygus lineolaris* (Palisot de Beaufois)
Clover root curculio, *Sitona hispidula* (Fabricius)
Potato leafhopper, *Empoasca fabae* (Harris)
Garden symphylan, *Scutigerella immaculata* (Newport)
Grape colaspis, *Colaspis brunnea* (Fabricius)
White grub, *Phyllophage* sp.
Seed-corn maggot, *Hylemya platura* (Meigen)
Other maggots

This listing suggests that many insects currently attack soybeans, but the estimated and potential losses they cause cover a great range. Insects attacking soybeans are of three basic types: (1) insects that attack seeds and seedlings, primarily underground; (2) aboveground foliage feeders; and (3) pod feeders. Insects also transmit diseases that infect soybeans. The species that attack the seed or root include wireworm, grubs, seed-corn maggots, and the seed-corn beetles. These pests generally attack the planted seed directly or the root system during the early stages of plant growth and become a problem when weather conditions or poor seed quality cause a delay in seedling emergence.

Maggots, grubs, and wireworms attack the seed and root in their larval stage. Their lack of mobility generally means they are confined to a limited area within a field. The pod feeders are primarily stink bugs and corn earworms. Infestations generally occur late in the season. Three primary species of stink bug attack the soybean pod. They damage the soybean seed by piercing the bean inside the pod. Young pods with small beans may cease to develop after they have been pierced and drop to the ground. Pierced beans in larger pods may be shrunken, wrinkled, and discolored in the puncture area. But generally these larger pods will remain on the plant. Soybeans may be downgraded in the market for this type of damage. Generally, stink bug infestation is more prevalent in the margins of field rather than across the entire area.

The corn earworm feeds on both the foliage and the pod. Small pods that are cut drop from the plant. On the more mature pods, the corn earworm chews holes in the pod covering and feeds on the beans inside.

The most common type of insect damage to soybeans is caused by the foliage feeders. The primary foliage feeders include: Mexican bean beetles, green cloverworm, loopers, bean leaf beetles, velvet bean caterpillars, blister beetles, and grasshoppers. Foliage feeders cause the plants to have a ragged appearance. However, a considerable amount of foliage loss is necessary before yield reduction occurs. The Mexican bean beetle has been a traditional pest of garden beans. However, it is becoming an increasingly serious problem on soybeans. Larvae feed exclusively on the underside of the leaves and give the leaf a lacelike structure, leaving the veins intact. The adult eats holes in the leaves and occasionally attacks the seed pod. Larvae of the green cloverworm and the cabbage and soybean looper are very common defoliators of soybeans. There may be several generations of these insects per year.

Table 2-6 presents an estimate of the present and potential losses from soybean insects. These pests have the potential of causing major losses within the sector. Generally the losses caused by insects are less in soybeans than in corn. Potential losses are estimated to range from 11 to 35 percent over the Corn Belt.

Soybean Diseases

Soybeans are subject to 30 or more diseases. Most are endemic in the Corn Belt, but a few occur only outside the United States. In contrast to corn, most soybean diseases never develop in epidemic proportions. However, a few of these diseases, unless controlled, can cause significant losses. These include the phytophthora rots and cyst nematodes.

Soybean diseases can be grouped into various types (Table 2-7). Individually, they cause mild to moderate losses; but, as in corn, effects are cumulative so that total losses may become significant. Lack of crop rotation in soybeans is more conducive to disease development than in corn. Some diseases are soil-borne, and quite adequate control is achieved through crop rotation. However, several diseases of soybeans are seed-borne.

Insects, Fungi and Other Pests Affecting Grain Quality in Transit and Storage

Soybeans usually have less mold problems in storage and transit than does corn. This is primarily because soybeans dry rapidly in the field. They mature earlier in

TABLE 2-6 Estimates of the Present and Potential Importance of Insect Pests on Soybeans

Insect	Losses with Present Controls: Special Local Areas	Losses with Present Controls: Cornbelt	Losses if Present Controls Were Not Used: Special Local Areas	Losses if Present Controls Were Not Used: Cornbelt
Mexican bean beetle	M	V	H	L
Green stink bug	L	VL	M	VL
Bean leaf beetle	L	VL	L	L
Green clover-worm	L	L	M	M
Wireworm	VL	VL	L	VL
Thistle caterpillar	L	VL	M	VL
Japanese beetle	L	VL	L	VL
Garden webworm	VL	VL	VL	VL
Grasshopper	L	L	M	L
Blister beetle	L	L	M	L
Spider mite	L	VL	M	L
Armyworm	L	VL	M	L
Tarnished plant bug	VL	VL	L	L
Leafhopper	L	VL	M	L
Garden symphylan	VL	VL	VL	VL
Grub	L	VL	M	VL

VL = Very Low (0-1%)
L = Low (2-10%)
M = Moderate (11-35%)
H = High (36-50%)
VH = Very High (over 51%)

NOTE: These estimates are based upon empirical data where available, and otherwise on the general knowledge and judgment of several scientists in the field.

TABLE 2-7 Infectious Soybean Diseases in the Corn Belt -- Present and Potential Importance in Causing Crop Losses

Disease	Causal agent	Losses with Present Controls in Effect		Potential Losses Should Present Controls Fail or Not Be Used	
		Local Areas	In Sector	Local Areas	In Sector
Seed decay	*Pythium* and other fungi	L	VL	L	VL
Seedling blight	*Pythium* and other fungi	L	VL	L	VL
Phytophthora rot	*Phytophthora megasperma* var. *sojae*	L	VL	H	L
Phyllosticta leaf spot	*Phyllosticta sojicola*	VL	VL	VL	VL
Brown spot	*Septoria glycines*	L	VL	L	L
Rhizoctonia root and stem rot	*Rhizoctonia solani*	L	VL	L	L
Bacterial blight	*Pseudomonas glycinea*	L	VL	L	L
Bacterial pustule	*Xanthomonas phaseoli* var. *sojensie*	L	VL	L	VL
Wildfire	*Pseudomonas tabaci*	VL	VL	VL	VL
Soybean mosaic	SM virus	M	VL	M	L
Bud blight	TRS virus	L	VL	L	VL
Downy mildew	*Peronospora manshurica*	L	VL	L	VL
Cyst nematode	*Heterodera glycines*	M	VL	H	M
Frogeye leaf spot	*Cercospora sojini*	L	VL	L	VL
Stem canker	*Diaporthe phaseolorum* var. *caulivora*	L	VL	M	L
Pod and stem blight	*D. phaseolorum* var. *sojae*	M	L	M	L
Alternaria leaf spot	*Alternaria* sp.	VL	VL	VL	VL
Brown stem rot	*Cephalosporium gregatum*	M	L	M	M
Charcoat rot	*Macrophomina phaseoli*	L	VL	L	VL
Purple seed stain	*Cercospora kikuchii*	VL	VL	VL	VL
Storage rot	*Aspergillus* and *Penicillium* sp.	L	VL	L	L

VL = Very low (0-1%) L = Low (2-10%) M = Medium (11-35%)
H = High (36-50%) VH = Very High (over 51%)

NOTE: These estimates are based upon empirical data where available and, otherwise, on the general knowledge and judgment of several scientists in the field.

the fall than corn and are harvested at a lower moisture content. But in wet autumns, soybeans may mold severely in the field if the harvest is delayed. This is more common in the southern than northern part of the Corn Belt. Soybean seeds reabsorb water rapidly, and several fungi invade them if storage is too moist and warm. This reduces both feeding and processing value. Besides, some aflatoxin production can occur on soybean meal. Aflatoxin-producing fungi are the same in soybean products as in corn, but the problem is less severe in soybeans. The aflatoxin problem is generally less severe in the Corn Belt than in southern areas.

Seed Production Problems

Hybrid Seed-Corn Production

Hybrid corn will yield more than open-pollinated corn because of its hybrid vigor (heterosis effect). Improved standability contributes directly to actual yield and even more to machine-harvested yield. Hybrids have been developed with resistance or improved tolerance to specific diseases and some insects. Highly population-tolerant hybrids raise the potential yield and allow farmers to more effectively utilize fertilizers and other production inputs.

Grain harvested from hybrid corn plants and replanted usually yields 15-20 percent less than the F_1 hybrid. Hence, seed is purchased by the farmer every year. Annual seed production is absolutely crucial to the commercial use of hybrid corn.

The development of corn hybrids can be reduced to two basic steps:

1. Develop a series of inbred lines, each of high genetic uniformity, from repeated self-fertilization. (Originally, the source of inbred lines was open-pollinated varieties. Since about 1940, many of the new lines have come from crosses between inbreds followed by inbreeding and selection.)
2. Cross two inbred lines and test for yield and other desirable attributes in the single crosses.

The actual procedures used in performing these two basic research steps are complicated. Hundreds of thousands of plants are studied each year. The production of hybrid seed corn on a commercial basis always includes the following three components:

1. Maintenance of seed stocks for the inbred parents.
2. Increase of seed of the inbred parents to plant seed fields.
3. Production of single-cross hybrid seed.

Sometimes three-way or double-cross seed production requires an added crossing stage.

The basic supply of inbred lines is maintained by selfing or sib-mating with hand pollination to reduce the possibility of contamination by off-type pollen. To avoid foreign pollen, this seed is grown in isolated plots, and the supply of the inbred parents is built up to the amount needed for planting fields for hybrid seed production.

To produce single-cross seed, two inbred lines are planted in alternating strips through the field, commonly four seed (female) rows and two pollen (male) rows. Plants within female rows are prevented from pollinating themselves or each other by detasseling or by use of a male sterility system.

There are three types of hybrids--single cross (two inbreds), three-way cross (single-cross seed parent and inbred line pollen source), and double cross (two single crosses each made up of two previously crossed inbred lines).

Yield obtained from a seed field depends on the inbred line or lines used as the seed parent (female). For single crosses, the seed harvested from 1 acre (an inbred line) will plant about 200 acres of commercial corn. For three-way or double crosses, seed from 1 acre (a single cross) will plant more than 500 acres of commercial corn.

The cultural practices used for seed fields are similar to those employed by farmers for commercial corn production. But because of the crucial importance of seed production for the commercial crop in the following year, the extra value of seed fields, and the fragility or lack of competitiveness of the inbred lines, extra measures for care and protection are followed. Highly productive fields are selected for seed production, optimum fertilizer programs are followed, and herbicides and insecticides are carefully selected and applied.

Herbicide selection is more critical for inbred lines, because some are more susceptible to injury than their hybrid counterparts. Certain inbred lines are more susceptible to aphid damage than hybrids, so insecticide spraying is more commonly practiced. Fungicides generally are not used for disease control in seed fields other than as seed treatments, but they are sometimes applied to susceptible female parents to control fungal leaf blights. Disease problems can be serious, especially when a susceptible line (used because of other desirable attributes) is crossed with a resistant inbred to produce a resistant hybrid.

Soybean Seed Production

Soybeans are a self-pollinated crop, and varieties planted by farmers are essentially inbred lines. Seed harvested by a farmer, if free from disease and of adequate germinability, can be replanted without loss in yield. The seed from 1 acre of soybeans will plant about 35 acres the following year. More acres of soybeans (about 3 percent of the total crop) must be devoted to seed production than of hybrid corn (0.2-0.5 percent of the total crop).

Although any farmer can produce his own seed, harvesting, storing, and cleaning to assure good germination and vigor require special care. As a result, the number of farmers who save their own soybean seed is falling. Specialized companies or individuals, usually under the auspices of state crop-improvement associations, generally handle seed production. Seed fields are not generally treated differently than commercial fields with respect to herbicides, insecticides, or fungicides.

Regulation of Seed Production Activities

The developer of a new soybean variety can restrict its production and marketing under regulations established by the Plant Variety Protection Act. Application for protection under the act is voluntary. Hybrid corn generally is not protected, because the owner of the inbred seed supply typically controls production of the hybrid.

Shipment of seeds in interstate commerce must comply with regulations of the Federal Seed Act, which includes provisions for proper labeling. Each state maintains regulations for the sale and distribution of seeds. Laws vary among states, but regulations are similar. An association of state regulatory agencies attempts to minimize differences. State laws generally are similar to regulations under the Federal Seed Act.

Much of the soybean seed produced and marketed is "certified seed." Certification is a voluntary program established for those who wish to produce high-quality seed of known genetic purity. It also provides assurance to the farmer that he is getting pure seed of the designated variety. Under the Plant Variety Protection Act, a developer may permit only marketing of certified seed of his variety.

3

CURRENT PRACTICES IN CONTROL OF CORN AND SOYBEAN PESTS

PEST CONTROL IN CORN PRODUCTION

Weed Control--Corn

Weed control in corn is based on a combination of tillage, cultivation, and chemical herbicide treatments. The trend in recent years has been toward reduced use of tillage and cultivation and increased use of herbicides. However, seedbed tillage is still widely used and can greatly reduce weed problems, especially those of perennials. Many soil-applied herbicides are ineffective against the deep-rooted perennial weeds such as Canada thistle. Therefore, destruction of top growth and the root or rhizome system by tillage greatly reduces their ability to gain an early competitive advantage on the corn. Final seedbed tillage immediately prior to planting eliminates growing weeds that, if not destroyed, would have a strong competitive advantage over corn that germinates and emerges later. After the corn has emerged, harrowing or rotary hoeing can be used for a short period to destroy weeds shortly after germination. However, the row cultivator is the major implement used for weed control. By combining cultivation with herbicide treatments, the number of cultivation per season can be reduced from three or four times without herbicides to one time with herbicides. Occasionally, when herbicides are used, no cultivation is necessary, because chemical weed control is adequate.

The herbicides available or being evaluated for use in corn are listed in Table 3-1. To determine herbicide usage, weed scientists in the Corn Belt were asked for their estimates. An estimated 81 percent of the corn acreage in the Corn Belt area was treated with herbicides in 1973. This estimate is consistent with a USDA figure of 83 percent in 1972 (North Central Weed Control 1972).

TABLE 3-1 Herbicides Cleared or Being Evaluated for Weed Control in Corn Production in the North-Central Region

Greatest Use	Annual Use--Active Ingredient (1,000 lb)[a]	Substantial Use	Annual Use--Active Ingredient (1,000 lb)[a]	Limited Use	Annual Use--Active Ingredient (1,000 lb)[a]	Experimental
Alachlor	7,133	CDAA	479	Ametryne	[b]	AC-92553
Atrazine	42,677	Cyanazine	509	Chloramben	44	BAS-72461x
Butylate	4,107	Dicamba	267	Chlorbromuron	(New)	Bentazon
2,4-D	7,065	EPTC	266	Cyprazine	(New)	Bifenox
Propachlor	21,209	Linuron	767	Dalapon	[b]	DS-5328
		MCPA	158	Diallate	[b]	Glyphosate
		Simazine	766	Dinoseb	[b]	H-25893
				Diuron	[b]	M-3785
				Paraguat	[b]	NIA-21844
						NIA-23486
						R-31401

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[a] Summarized from Delvo (1972).

[b] Data not reported.

The effectiveness of herbicides on major weed species found in corn is given in Table 3-2. On the basis of this information, corn producers can select the herbicide most effective for their specific weed problems.

Herbicides may be applied before planting (preplant), before crops emerge (preemergence), or after emergence of the weeds or crops (postemergence).

Preplanting Applications

The herbicide most widely used in preplanting applications, butylate, is used on approximately 8 percent of the corn acreage. It is effective on grassy weeds but controls rather few broadleaf weeds. It and a chemically-related compound, EPTC, must be incorporated into the soil to reduce losses by volatilization. The use of protectants, napthalic anhydride, or N,N-diallyl-2, 2-dichloro-acetamide, is a recent development that increases corn tolerance to butylate or EPTC and allows the use of higher application rates. This gives improved control of troublesome weeds such as quack grass and yellow nutsedge. Atrazine can be mixed with these compounds to improve broadleaf weed control.

Preemergence Applications

Atrazine, most often applied in preemergence applications, is used more extensively in corn than any other herbicide. Approximately 40 percent of the corn acreage is now treated with this compound. It is effective on a large number of broadleaf weeds and is fairly effective on many grassy weed species. It is rather persistent in the soil, and injury to sensitive crops such as small grains or soybeans planted the following season is a possibility. Mixtures of atrazine with effective grassy weed herbicides are often used to improve grassy weed control and to reduce the rate of atrazine application so carry-over effects are reduced.

Cyanazine, chemically similar to atrazine, has been introduced recently for use in corn. It is approximately equal to atrazine in effectiveness on weeds and is less persistent. It is a good alternative where atrazine persistence is a problem. Propachlor and alachlor, chemically related herbicides used in preemergence on more than 25 percent of the corn acreage, are very effective on annual grassy weeds and also will control a few broadleaf species. Preemergence applications of chlorobromuron,

TABLE 3-2 Effectiveness of Herbicides on Major Weeds in Corn

	Preplanting			Preemergence								Postemergence					
	Butylate	EPTC	Atrazine	Alachlor	Atrazine	Simazine	Dicamba	Propachlor	Linuron	Chlorbromuron	Cyanazine	2,4-D	Dicamba	Atrazine	Cyanazine	Ametryne	Paraquat[a]
Grasses																	
Giant foxtail	G	G	F	G	F	F	P	G	F	F	G	N	N	P	F	G	G
Green foxtail	G	G	G	G	G	F	P	G	F	F	G	N	N	F	F	G	G
Yellow foxtail	G	G	G	G	G	F	P	G	F	F	G	N	N	F	F	G	G
Panicums	G	G	P	G	P	F	P	G	F	F	F	N	N	P	F	G	G
Quack grass	N	F	G	N	G	F	N	N	N	N	P	N	N	G	P	P	F
Yellow nutsedge	F	G	P	F	P	P	N	F	P	P	P	N	N	P	P	F	F
Shattercane	G	G	P	P	P	P	N	P	P	P	P	N	N	P	P	G	G
Johnson grass, seedling	G	G	P	F	P	P	N	G	P	P	P	N	N	P	P	-	G
Johnson grass, rhizone	P	P	N	N	N	N	N	N	N	N	N	N	N	P	N	P	F
Crabgrass	G	G	P	G	P	F	P	G	G	G	F	N	N	P	F	G	G
Barnyard grass	G	G	F	G	F	F	P	F	F	F	F	N	N	F	F	G	G
Broadleafs																	
Pigweed	F	F	G	G	G	G	G	F	G	G	F	G	G	G	F	G	G
Velvetleaf	F	F	F	P	F	F	F	P	F	F	F	G	G	F	F	G	G

TABLE 3-2 (Continued)

	Preplanting			Preemergence							Postemergence					
	Butylate	EPTC	Atrazine	Alachlor	Atrazine	Simazine	Dicamba	Propachlor	Linuron	Chlorbromuron	Cyanazine	2,4-D	Dicamba	Atrazine	Cyanazine	Ametryne	Paraguat[a]
Broadleafs (continued)																	
Canada thistle	N	N	P	N	P	N	N	N	N	N	P	F	G	F	P	P	F
Cocklebur	P	P	F	N	F	F	F	P	P	P	F	G	G	G	F	G	G
Wild sunflower	P	P	F	P	F	F	F	P	P	P	F	F	G	G	F	G	G
Lamb's quarters	P	F	G	F	G	G	G	P	G	G	G	G	G	G	G	G	G
Smartweed	P	P	G	P	G	G	G	P	F	F	G	P	G	G	G	G	G
Morning glory	P	P	G	P	G	F	F	P	F	F	G	G	G	G	G	G	G
Common milkweed	N	N	P	N	N	N	N	N	N	N	N	P	F	P	P	P	F
Field bindweed	N	N	N	N	N	N	P	N	N	N	N	G	G	P	P	P	F
Mustard	P	P	G	P	G	G	G	P	G	G	G	G	F	G	G	G	G
Ragweed	P	F	G	P	G	G	G	P	G	G	G	G	G	G	G	G	G
CORN TOLERANCE	G	F	G	G	G	G	F	G	F	F	G	F	G	G	G	P	N

G = Good F = Fair P = Poor N = None

[a] Must be applied prior to corn emergence.

recently introduced and not yet used extensively, provide fair control of grassy weeds and good control of broadleaf weeds.

Preemergence applications of herbicide mixtures used in corn control a broader spectrum of weeds. Atrazine mixtures with alachlor, propachlor, or linuron are cleared for use on corn. Other mixtures are cyanazine plus alachlor, linuron plus propachlor, and dicamba plus alachlor or chlorbromuron.

Postemergence Applications

Substantial acreages of corn are now also treated with postemergence applications of herbicides. Atrazine plus nonphytotoxic oils, applied when weeds are small, is used extensively on about 15 percent of the corn acreage in the Corn Belt. Cyanazine and cyprazine, chemically related to atrazine, are used on limited acreages. The other major herbicide used in postemergence applications, 2,4-D, is used on approximately 15 percent of the acreage and is only effective on broadleaf weeds. Dicamba, an alternative to 2,4-D, is very effective on broadleaf weeds and is gaining in usage. Soybeans, however, are highly sensitive to dicamba, the use of which is restricted by drift injury from corn spraying. Directed postemergence sprays, applied only to the base of the corn plant when it is at least 15 inches tall, can be used as an emergency measure to control heavy weed stands within the row. Linuron and ametryne are safe to use in this manner. Very limited acreages are now treated in this way. The substantial list of experimental herbicides in Table 3-1 indicates a continuing interest of the agricultural chemical industry in developing new herbicides for use in corn. This interest provides alternative chemicals that may improve the overall effectiveness of weed control or may give better control of specific weeds than is now possible.

Insect Control--Corn

Insect control practices in corn can be divided into three basic categories: (1) chemical, (2) biological, and (3) cultural. Another broad division refers to the type of action taken, namely, corrective or preventative.

The primary tool currently available to control economically damaging insects in corn is chemical insecticides.

A survey of insecticide usage estimates that 50-60 percent of the corn acreage is treated annually with an insecticide. The major portion of this is applied to the soil primarily for control of insects such as corn rootworm, cutworms, wireworms, and grubs. It is estimated that more than 90 percent of these applications are made prior to or at the time of planting. The four primary methods of application in order of use are: (1) band, (2) broadcast, (3) furrow, and (4) starter fertilizer applications.

The method used depends on the species of insect to be controlled, formulation of the pesticide, and availability of specific application equipment. Historically, granular insecticides have been broadcast to control cutworms, wireworms, and grubs. However, the practice of broadcast application of insecticides is declining. Currently, the primary method for applying soil insecticides is in a 7-in. band over the seed row as an integral part of the planting operation. The insecticide is incorporated in the soil and is designed to control corn rootworm larvae. Estimates indicate that this is the application method used on some 90 percent of the acreage treated for this pest. The furrow method involves placing the insecticide directly in the furrow or channel that is opened in the soil for seed placement. Primary target species for this method are wireworms, seed-corn beetles, and maggots. A lesser number of acres is treated by this method as compared with broadcast and band application. The application of a combination starter fertilizer and insecticide is a minor practice, and the quantity applied in this way is very small.

Recommendations for soil insect control using the broadcast and band application methods require that the insecticide be incorporated with the soil. Incorporation is recommended, because it enhances effectiveness and minimizes the potential for loss in water runoff. These insecticide applications (primarily for rootworm and cutworm) are made prior to the time when the damaging stage of the insect is present in the field. The need for treatment is based primarily on the number of adults in the field the preceding year and an analysis of the egg load.

Postemergence treatment to control soil insects is used on a limited basis and serves primarily as an emergency control. When used, it is applied either as granules or a spray directed at the base of the corn plant. This is done as an integral part of the cultivation process. Application at cultivation time has given more erratic results than application at planting time.

Seed treatment is used to control seed-corn beetles, seed-corn maggots, and, to a lesser extent, wireworms. The seed may be treated either by the seed company or the farmer at planting.

Foliar application is used primarily to control corn leaf aphids, mites, flea beetles, corn earworm larvae, European corn borer larvae, and corn rootworm adults. Spray application is used in these cases, except for first generation European corn borer, where granules are often used. Under some conditions the control of adult rootworms may be an important consideration manipulating the larvae population the following year.

The primary technology available today for control of insects attacking corn is chemical pesticides. There is an increased awareness and concern about current practices in the application of pesticides. The trend in corn production is away from the use of environmentally persistent insecticides, such as aldrin and heptachlor, to less-persistent materials, such as furadan, diazinon, etc. Over the years, this shift has occurred for several reasons: (1) development of more effective insecticides that have less persistence, (2) development of resistance by a primary target pest (western corn rootworm) to aldrin and heptachlor, and (3) growing concern for environmental effects. In recent months, a ban on the agricultural uses of aldrin and dieldrin was imposed by the Environmental Protection Agency after extensive study. This legal restraint only hastens forces that were already at work in the corn/soybean sector.

Generally, the nonpersistent insecticides are 2-5 times more expensive than the persistent ones. The organophosphate and carbamate insecticides have almost completely replaced the cyclodiene compounds for control of rootworm larvae. A sharp increase in the number and frequency of control failure has been noted with the organophosphate and carbamate insecticides during the past several growing seasons. Large-scale resistance to these compounds may be developing. Resistance to the cyclodiene insecticides developed after about 12 seasons of use. Some of the present organophosphates already have been used for an approximately equal period. The development of insecticide cross-resistance is well-documented with other insect species. Since some of the organophosphates and carbamates are losing effectiveness, the control of corn rootworm larvae may become a serious problem.

The historical evolution of insect control practice and technology can be viewed in three basic stages: (1) the pre-1940 era in which substances such as arsenic, copper, sulfur, nicotine, and pyrethrum were the primary tools available; (2) the post-1940 era in which synthetic insecticides (first the chlorinated hydrocarbons, then the organophosphates and the carbamates) came into use; and (3) the emerging era of integrated pest management that emphasizes the synthesis and utilization of a range of control strategies including chemical insecticides.

The major emphasis in this new era is: (1) reduction of indiscriminate routine applications of insecticides; (2) improvement in dosage, targeting, and application methods; and (3) integration of chemical and nonchemical pest control technologies. However, it is generally agreed that a significant portion of the insecticides applied to control soil insects in corn is a prophylactic or insurance treatment. Today the capability to predict the need for treatment to control soil insects, especially cutworms, wireworms, grubs, seed-corn maggots, and beetles is minimal. Consequently, corn growers who have encountered soil insects once on their farms often continue to apply chemical insecticides routinely year after year without reexamining the actual need for treatment.

The term "integrated pest management" implies the development and utilization of a broad spectrum of methods and techniques for combating insect pests. One aspect of this management scheme involves cultural practices. Various cultural practices have differential impacts on corn insect problems as is evident in Table 3-3. For example, continuous corn production results in the reduction of cutworm and wireworm problems while increasing the level of corn rootworm problems. Thus, an annual rotation program practiced over an extensive area would likely reduce the corn rootworm to a nonsignificant pest level and, thereby, eliminate the need for insecticide treatment to control this species.

Obviously, crop rotation is an effective practice that can be used as an alternative to insecticide application. However, the table indicates that other soil insect problems such as cutworms and wireworms would be increased. These insects are more difficult to control than corn rootworm, and their occurrence is virtually impossible to predict as compared with the ability to predict the rootworms. Consequently, a significant amount of routine prophylactic treatment for cutworm and wireworm occurs. Thus, farmers often forego rotation and plant corn for several years in a row partly because of the advanced chemical technology in corn rootworm control practices. Though many cultural practices have an effect on pest populations, as indicated in Table 3-3, none of the

TABLE 3-5 Effect of Various Factors on Insect Populations and/or Potential Damage in Corn in 11 North-Central States[a]

Insect	Planting Time		Rotation[b]			Minimum Tillage	Commercial Fertilizer	Weeds	Hybrid Resistance	Biol.[c] Controls
	Early	Late	Cont. Corn	Corn-Soybeans	Corn-Hay (or Past.)					
Seed-corn beetle	+	-	0	0	+	+	0	0	No	?
Seed-corn maggot	+	-	0	0	+	+	0	0	No	?
Wireworm	+	0	-	-	+	+	0	0	No	?
White grub	?	-	-	+	+	+	-	-	No	Yes
Corn root aphid	-	+	-	-	+	?	-	+	Yes	?
Grape colaspis	+	-	-	-	+	+	-	0	No	?
N. corn rootworm	-	+	+	-	-	-	-	-	Yes	No
W. corn rootworm	-	+	+	-	-	-	-	-	Yes	No
S. corn rootworm	-	0	0	0	0	?	-	+	Yes	No
Black cutworm	+	-	0	+	0	+	0	0	No	No
Billbug	0	0	-	-	+	+	0	+	No	?
Slug	?	?	-	-	0	+	0	0	No	?
Thrip	-	+	0	?	+	+	-	0	Yes	?
Mite	?	+	0	0	0	+	+	0	?	?
Eur. corn borer	+	-	0	0	0	0	+	0	Yes	Yes
S.W. corn borer	-	+	0	0	0	0	-	0	No	Yes
Earworm	-	+	0	0	0	0	0	0	Yes	Yes
Fall armyworm	-	+	0	0	0	0	0	0	No	Yes
True armyworm	-	+	0	0	+	+	0	+	No	Yes
Chinch bug	-	+	0	0	+	+	-	-	Yes	?
Corn leaf aphid	-	+	0	0	0	0	+	+	Yes	Yes

+ = Increase in insect population or damage
- = Reduction in insect population or damage
0 = No effect
? = Effect unknown

[a] Compiled by Dr. H. B. Petty, Extension Entomologist, Illinois Natural History Survey, from research results and views of entomologists in North Central region.

[b] Sorghum and irrigation not included.

[c] Includes insect disease, parasites, and predators.

practices are as effective as rotation in suppressing corn rootworm populations.

There are biological methods of control (disease, parasites, and predators) that play a major role in regulating the population pest species. However, there is at present virtually no purposeful manipulation of these biological organisms for the control of any pest species in corn.

Plant resistance to insects can be included in the broad area of biological methods of control. Strains that are resistant to the first generation of the European corn borer have been developed. A number of commercial hybrids currently carry genetic resistance. Sources of resistance to the corn leaf aphid and plant tolerance to root feeders such as corn rootworm larvae have been identified. However, these characteristics have not been incorporated in hybrids that are available to the grower. Plant resistance may serve as a primary means of control for the first-generation European corn borer or as an adjunct to other control methods. For the future, the development of insect-resistant varieties may become a satisfactory alternative to insecticide treatments.

Currently five states (Indiana, Iowa, Illinois, Ohio, and Missouri) are involved in a cooperative pest management action program in corn. The goals of the program are: (1) to implement an insect pest management system for corn that will benefit both agriculture and the environment, (2) to educate growers in the concept and implementation of such management, and (3) to analyze its costs and benefits. It is expected that this project will form the base for an improved insect control program throughout the corn/soybean sector. The major early benefits should be to improve the targeting of pesticides.

To illustrate some common methods of insect control, specific techniques recommended by the Indiana Agricultural Extension Service for dealing with the western corn rootworm and European corn borer are summarized below.

Corn Rootworm

Where corn follows corn in the cropping sequence, the possibility of a western corn rootworm attack exists. However, many cornfields have few, if any, beetles during the August oviposition season, so that a rootworm problem in these fields is unlikely the next season.

Check for beetles. In those cornfields that will be planted to corn again next season, a check during August will tell if rootworm controls might be needed. During the period when the field is in green silks, look for the western rootworm beetles. If fewer than one beetle per plant is found, chances are good that no problem will exist in that field next year. If one or more beetles per plant can be found, the field may have a rootworm problem.

Crop rotation. Plant the field to some crop other than corn to avert a rootworm problem.

Insecticide application. Many insecticides are available that do a good job controlling western corn rootworm larvae. Apply these insecticides at planting time as a 7-in. band over the row. For best results, incorporate such a band lightly into the soil with the press wheel of the planter. You can apply insecticides later in the season as a cultivation treatment. The cultivation treatment must be applied at the time when rootworm larvae are beginning to feed on the corn roots, generally about the first week of June. Cultivation treatments can be either a "basal application," where the insecticide is applied at the base of the plant, or an "over the row" treatment, where the insecticide is dropped over the whorl of the corn plant with 80 percent of the granules falling to the ground. Both applications must be accompanied by cultivation to be effective.

Cultivation treatments compare favorably with planting time treatments for rootworm control; however, timing of the application is critical and is the major disadvantage of such a treatment. Cultivation treatments have some plus factors, however:

1. The insecticide is applied nearer the time it is needed, thus reducing the chances of insecticide failure owing to length of effective life.
2. Combination corn borer and rootworm control can sometimes be achieved with one application of an insecticide, which is recommended for both corn borer and rootworms.
3. It is possible to establish the existence of rootworm problems before the insecticide is applied.

Criteria for applying corn soil insect control.

1. If land is in continuous corn and has not had a recent history of soil insect problems, a soil insecticide is not recommended.

2. If land has continuously been treated with aldrin, heptachlor, or chlordane (Belt) and no recent soil insect problems are apparent, chemicals are not recommended until a problem occurs.

3. (a) If counts of western and/or northern corn rootworm beetles average one or less than one beetle per plant (feeding on green silks during August), no soil insecticide is recommended the following year -- if that field is planted to corn.

(b) If counts of western and/or northern corn rootworm beetles average more than two western or more than four northern species per plant, you can expect a rootworm problem if you plant corn in that field the next year. Either rotate that field to some other crop in which volunteer corn plants are not allowed to develop, or if you plant corn, apply a soil insecticide.

(c) If western beetles average one to two per plant or northerns two to four per plant, the need for treating depends upon date of planting, soil type, and suitable moisture for the rootworms to develop.

(d) If control of rootworms is required, use the appropriate material listed. Check product labels for fertilizer combinations, lay-by applications, and for any specific restrictions, warnings, precautions, and for reentry or harvest intervals.

4. If the land has had a recent history of soil insect problems other than rootworms, select and apply an insecticide in a manner that will control the specific problem.

5. If the land was in sod and/or legumes the previous year, or if a green manure crop is continuously plowed under, wireworms, cutworms, white grubs, sod webworms, and/or billbugs might be a problem; therefore, apply one of the recommended insecticides. On dairy farms and on corn to be chopped for silage, use labeled materials paying strict attention to any specific harvest restrictions.

Corn Borer

Cultural practices. Corn borer damage can be reduced by avoiding, if possible, extremely early or late planting. Farmers who are prepared to apply an insecticide for borer control, if need be, should plant as early as possible.

This practice may increase first-brood attack, which is easy to control with insecticides, but will reduce second-brood attack, which is difficult to control.

Plant hybrids that are adapted to your locality. Most adapted hybrids will stand up, hold their ears, and produce high yields in spite of corn borer attack.

Destroying corn stalks and other refuse in which the borers overwinter might help, but there is no evidence that such "cleanup" will reduce borer damage, even if conducted on a community-wide basis. For this reason, cleanup practices, such as plowing, stalk shredding, low cutting, and ensiling, are recommended only to the extent that they are good cultural practices.

Insecticide treatments. Corn borer can be controlled with insecticides *provided* they are correctly applied and at the right time. As a rule, one application will give satisfactory control of the first brood on field corn, but two or three applicatons might be needed against the second brood because egg-laying extends over a much longer period of time. For this reason, field corn in Indiana is seldom treated for control of the second-generation borer. Treatment with insecticides is usually practical on market sweet corn, canning corn, and hybrid seed fields. On field corn, treatment depends upon the degree of infestation.

When to treat. When field corn reaches 35 in. tall (stretched-up leaf), it should be inspected every day or two to determine the percentage of plants that are infested. Infested plants have small "shot-holes" in the whorl and on the upper leaves. These holes are caused by the feeding of the recently hatched borers. An insecticide application is justified if and when 75 percent of the plants show this type of fresh feeding.

Most treatments for corn borer control in Indiana have been applied too late for best results. In any one field there is no more than a week's time during which location of the borers on the plant is such that an insecticide will give maximum results. If treatment is delayed until borer damage becomes more evident, then it is too late. By this time, the borers may be nearly one-half grown and embedded too deep in the plant for an insecticide to reach them.

Control with granules. Best control of corn borers is obtained by applying the insecticide in granular form. This is because the granules lodge behind the leaf sheaths and in the plant whorl where most of the borers are or soon will be located. The granules can be applied with either ground or aerial equipment.

Control by spraying. Spray applications should be applied using a nozzle arrangement. By the time corn borer treatments are justified, most of the borers have already reached the plant whorl. For this reason, the spray must be applied directly into the plant whorl and behind the leaf sheaths. A spray is of little value if it is simply broadcast over the surface of exposed leaves.

Plant Pathogen Control--Corn

Disease control in corn can be divided into three categories: (1) cultural practices, (2) chemical protectants, and (3) genetic resistance. Genetic resistance is of far greater importance than the other two methods.

Cultural practices (such as crop rotation, destruction of diseased parts, plant spacing, timing of planting, and mineral nutrient application) can be used to lower the severity of some diseases. However, these practices are only partially effective in the Corn Belt, where corn is extensively grown. In addition, they may be incompatible with current management practices aimed toward high yields and larger sized production units. Intensive cultural practices needed for high productivity per acre often favor disease development.

Plant population levels, for example, need to be quite high for some corn hybrids to achieve their maximum harvestable yield. High plant density favors disease. Stalk rots can be more severe when corn is planted in soils deficient in potassium but where nitrogen levels are high. However, potassium applications greater than that needed to achieve a fertility balance do not control this disease. Destruction of crop refuse through deep plowing aids in disease control. Yet, to conserve energy and to protect soil loss through erosion, minimum- or no-tillage practices are being used increasingly. Where this is done, a traditional disease control practice, crop sanitation, is lost. Other control practices then are needed to make up for this deficiency.

Corn planting can be delayed in the spring until soils are warmer to control seed rots and seedling blights, but early planting is necessary to achieve high yields. Many of the cultural practices now common in the Corn Belt are used because of agronomic, edaphic, or economic reasons rather than for disease control. It is unlikely that these practices will be changed as a means of controlling disease as long as other effective disease control practices are available.

Chemical control of disease on the farm is mostly limited to the treatment of seed corn with a fungicide. These chemicals control seed rots and seedling diseases but not other diseases. Seed treatments are effective and easy and economical to apply. Nearly all corn seed planted is obtained from commercial seedsmen and treated by them with a fungicide or fungicide-insecticide combination before it is sold to the farmer. Genetic resistance to seed rot and seedling diseases is possible, but today fungicides provide the most feasible control. Mainly for economic reasons, spraying corn in the field with fungicides for disease control is not often done on the farm.

The most efficient way to control most corn diseases is to use adapted disease-resistant hybrids. Much progress has been made by plant breeders, pathologists, geneticists, and seedsmen in this area. Unfortunately, no single hybrid is both high-yielding and highly resistant to all diseases. In fact, some very useful hybrids are quite susceptible, and new diseases or races of current disease-producing pathogens continue to appear in the sector. Within the last decade, new disease problems have occurred, including maize dwarf mosaic, yellow leaf blight, eyespot, leaf freckles and wilt, southern leaf blight race T, maize chlorotic dwarf, sorghum downy mildew of corn, and helminthosporium leaf spot. It may be impossible to obtain high resistance to all diseases in a single hybrid. Yet on the basis of past experience, it should be possible to develop adapted, high-yielding hybrids that are resistant to the major diseases within given geographic or agronomic areas.

Corn breeders and pathologists currently rate hybrids and inbreds for some 24 different diseases, including leaf blights, rusts, anthracnose, ear rot, stalk rots, smut, downy mildew, and several bacterial and virus diseases. In any given period of time, not all diseases are important in all regions of the Corn Belt. Breeders and pathologists naturally pay most attention to those diseases that occur in the region where a particular hybrid is to be grown, so that the growth of a hybrid very susceptible to any one disease is avoided.

Disease resistance in the corn hybrid adds little to the cost of production at the farm level. Although the efforts of researchers and seedsmen may be considerable, as long as it is possible to develop and produce disease resistant hybrids competitively with susceptible hybrids, the resistant varieties will be sold. Farmers will elect to purchase the resistant hybrid seed rather than susceptible hybrids, since the latter may require the application of costly protectant fungicides in order to be productive.

By relying mainly on resistant varieties for disease control in corn, the capacity to deal immediately with an unexpected disease outbreak is limited. Even if resistant varieties for the new disease are known, it may take one or more growing seasons to multiply the basic resistant seed stock sufficiently for commercial distribution. If no resistant varieties are on hand, the problem is worsened since the time span required to deal with the outbreak and spread of the new disease is substantially lengthened.

PEST CONTROL IN SOYBEAN PRODUCTION

Weed Control--Soybeans

Weed control in soybeans, as in corn, is based on a combination of tillage, cultivation, and herbicide treatments. There has been a very rapid increase in herbicide usage recently with reduced emphasis on tillage and cultivation for weed control. Only 33 percent of the soybean acreage in the Corn Belt was treated with herbicides in 1966, while 80 percent of the acreage was treated in 1972, 7 years later (Delvo 1973a). The herbicides available or being evaluated for use in soybeans are listed in Table 3-4.

Cultural practices are of considerable importance in soybean weed control. Seedbed preparation immediately before planting kills weeds that are present and also slows weed seed germination. Use of the rotary hoe, harrow, and row cultivator substantially reduce weed populations. The rotary hoe and harrow are only effective on weeds just as they emerge, while the row cultivator can be used until the soybean plants start to fill in between rows.

Herbicides can be used before planting, preemergence, or postemergence. Soybean growers are now selecting herbicides that will control the specific weeds most troublesome in their own fields. Estimates on the effectiveness

TABLE 3-4 Herbicides Cleared or Being Evaluated for Weed Control in Soybeans and Usage in the North Central Region[a]

Greatest Usage	Annual Use--Active Ingredient (1,000 lb)[a]	Substantial Usage	Annual Use--Active Ingredient (1,000 lb)[a]	Limited Usage	Annual Use--Active Ingredient (1,000 lb)[a]	Experimental
Alachlor	5,002	Chlorpropham	303	Bentazon	(New)	Bifenox
Chloramben	8,960	Dinoseb	689	CDAA	5	Fluchloralin
Trifluralin	3,901	Fluorodifen	1,134	2,4-DB	105	Glyphosate
		Linuron	648	Chloroxuron	[b]	HOE-22870
		Naptalam	389	Dinitramine	(New)	HOE-23408
		Propachlor	469	Metribuzin	(New)	Profluralin
		Vernolate	247	Nitralin	14	

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[a] Data summarized from Delvo (1973b).
[b] Data not reported.

of herbicides on specific weed species found in soybeans are given in Table 3-5.

Preplanting Application

The herbicide most widely used as a preplanting treatment is trifluralin. It is used on about 22 percent of the soybean acreage. It must be incorporated in the soil to minimize volatility losses. Applications can be made from the previous fall until immediately prior to planting. It is most effective on grassy weeds. Dinitramine and nitralin, related to trifluralin, and vernolate may also be incorporated before soybeans are planted for control of most grassy weeds and a few broadleaf species.

The herbicide most widely used preemergence is amiben. It is used on about 35 percent of the Corn Belt soybean acreage and must be applied prior to weed seed germination. It is effective on most of the major broadleaf and grassy weed species. Another herbicide used preemergence on extensive acreages, alachlor, is used on about 17 percent of the soybean acreage. It is very effective on grassy weeds but controls only a few broadleaf species. Propachlor, chlorpropham, linuron, fluorodifen, and metribuzin are used in preemergence applications. Fluorodifen and metribuzin are recently introduced herbicides that may come into more extensive usage as soybean farmers gain experience with them.

Postemergence applications of 2,4-DB and chloroxuron have not been used extensively because of limited soybean tolerance to them and some lack of effectiveness in weed control. A promising new herbicide, bentazon, with an experimental label clearance, is much less likely to injure soybeans and controls a substantial number of broadleaf weeds. Once full label clearance is obtained, it probably will become widely used.

Insect Control--Soybeans

Insecticide use on the soybean crop has increased considerably in the past few years. The increased total acreage of soybeans has been a factor. The crop is now being planted in areas and under conditions that are more conducive to insect problems. This is especially true in the southern areas of soybean production (see Figure 1-2).

In addition, the recent price level of soybeans has been strong. This encourages producers to maintain close

TABLE 3-5 Effectiveness of Herbicides on Some Major Weeds in Soybeans

	Pre-planting			Preemergence						Post-emergence		
Plant Species	Trifluralin	Nitralin	Vernolate	Alachlor	Fluorodifen	Chloramben	Chlorpropham	Linuron	Metribuzin	Chloroxuron	2,4-DB	Bentazon
Soybean tolerance	F		F	G	G	G	G	F	F	F	P	G
Grasses												
Giant foxtail	G	G	G	G	G	G	P	F	F	P	N	N
Green foxtail	G	G	G	G	G	G	P	F	F	P	N	N
Yellow foxtail	G	G	G	G	G	G	P	F	F	P	N	N
Barnyard grass	G	G	G	G	F	G	P	F	F	P	N	N
Yellow nutsedge	P	P	F	G	P	P	N	P	P	N	N	F
Panicums	G	G	G	G	G	G	F	F	F	P	N	N
Shattercane	G	G	G	G	-	P	P	P	P	P	N	N
Crabgrass	G	G	G	G	G	G	F	G	F	P	N	N
Johnson grass	P	P	P	P	P	P	P	P	P	N	N	N
Quack grass	P	P	P	P	P	P	P	P	P	N	N	N
Broadleafs												
Cocklebur	P	P	P	P	P	P	P	P	F	F	F	G
Lamb's quarters	G	G	G	F	F	G	P	G	G	F	P	F
Mustard	N	N	F	P	F	F	F	G	G	G	P	G
Pigweed	G	G	G	G	G	G	P	G	G	F	P	F
Common ragweed	N	N	P	P	F	G	P	G	G	P	P	G
Smartweed	P	P	P	P	G	G	G	F	G	P	P	G
Velvetleaf	P	P	F	P	P	F	P	F	F	P	P	G
Wild sunflower	N	N	P	P	P	P	P	P	F	F	P	G
Black nightshade	P	P	P	G	G	F	P	P	P	P	P	G
Morning glory	P	P	F	P	F	P	N	F	P	F	F	F
Climbing milkweed	N	N	P	P	F	N	N	P	-	P	P	-
Common milkweed	N	N	N	N	N	N	N	N	N	N	N	P
Field bindweed	P	P	N	N	N	N	N	N	N	N	P	-
Canada thistle	N	N	N	N	N	N	N	N	N	N	P	F
Jimson weed	N	N	P	P	P	P	N	F	G	G	P	G

G = Good F = Fair P = Poor N = None

scrutiny of their crop. When damage such as leaf feeding is observed, the typical response is to treat the crop immediately with insecticides even though little potential for sustaining loss actually may exist. Since insecticides represent a relatively small cost in soybean production, growers will readily adopt them in order to be certain they do not sustain losses caused by insects.

The primary insect damage in soybeans is leaf feeding. This damage is readily observed by the grower and represents a strong stimulus to treat the "problem." Research has demonstrated that soybeans can tolerate considerable defoliation without yield loss. Current insect control recommendations are based on (1) percent defoliation at a given stage of development and (2) number of insects per unit (plant or row). These thresholds for treatment have been based on simulated damage and pest-defoliation studies and can be continuously adjusted for actual or expected changes in the market price of beans.

The decision to control insects must be based on the insect population, stage of development of the insect and crop, an estimate of the existing leaf damage, and potential crop yield. For example, a relatively low population of foliage-feeding larvae pose a greater potential for loss than a high population of more mature larvae. In addition, the presence of parasites, predators, and diseases of the insects must be considered in making decisions about chemical treatments. At certain times, insect diseases play an important role in controlling such insects as the velvet bean caterpillar and the soybean looper. The presence of diseased larvae is generally an indication that an infestation may be in its terminal phase.

The insect population is generally estimated by shaking plants over a space that has been covered with a sheet of paper or cloth. Such insect counts are made in several locations throughout the field at regular intervals. It is crucial for an effective pest management system that observed insect species be properly identified. Photographs and illustrations are available that aid the scientist or consultant in estimating the degree of defoliation. The interaction of insect population, stage of insect development, crop maturity, and degree of defoliation must be considered in the decision to treat or not treat an infestation. For example, prior to full bloom, soybeans can tolerate a remarkable degree of defoliation (some scientists estimate as high as 50 percent) without adverse effects on yield. However, at initiation of bloom through pod filling, leaf loss becomes quite critical, with some date indicating that 5-15 percent foliage loss during this period has a significant depressing effect on yields. There are data to suggest that varietal differences exist with regard to the degree of defoliation and its effect on yield.

A typical recommendation on the timing of insecticide application for foliage might include the following: Pre-bloom growth stage -- treat when greater than 40 percent defoliation. Blooming to pod fill -- treat when greater than 25 percent defoliation. Full pod to harvest -- treat when greater than 35 percent defoliation.

The insect control practices on soybeans are at a similar stage of development as those on corn were about 25 years ago. A relatively limited quantity of insecticide currently is being used on the soybean crop as compared with corn. However, the annual application of insecticides on soybeans is estimated to have increased 30-40 percent in each of the past 2 years. Currently, it is estimated that 3-4 million acres were treated with insecticides in the sector during 1973.

Control of insects attacking soybeans can be achieved with a number of insecticides. The primary chemicals used include Sevin, Malathion, Di-syston, Guthion, Toxaphene, and Methyl parathion. The effective rates range from 0.25 to 3 lb per acre and are dependent on the chemical used, time of application, and pest species. In contrast with corn, soybeans do not have a single pest that accounts for a major portion of insecticide applications. Also in contrast with corn, soybeans are subject to a greater number of sporadic, explosive, and potentially destructive insect pests. Several of these have the potential to become severe pest problems. The producer currently can obtain adequate insect control with registered chemicals. Substantial species resistance to pesticides has not been documented for the present soybean insect complex. However in view of experience with similar pests in other crops, the development of insecticide resistance should be anticipated.

The primary nonchemical alternative currently available is *Bacillus thuringensis*. This bacterium has given varied results when used to control some of the lepidopterous larvae. Research programs now under way indicate that some insect control by several alternative methods is clearly possible. These alternatives include plant resistance, microbial pathogens, and the manipulation of parasites and predators. Though biological control agents are known to play a significant role in natural population fluctuations, the purposeful manipulation of these agents has not yet been achieved.

Varieties that are resistant to leaf feeding by several species have been identified. These germ plasm sources are being utilized in several breeding programs to develop resistant varieties that can be released to the grower. It is estimated that soybean varieties with resistance to leaf feeding will be available to the grower in 3 to 5 years.

Plant Pathogen Control--Soybeans

Plant disease control in soybeans is achieved almost entirely through cultural practices and genetic resistance. A plant quarantine has been used to limit the spread of the soybean cyst nematode and, thereby, protect the crop grown in uninfested fields. Since there is usually little advantage in treating seed with fungicides, it is rarely done. However, when the quality of seed is poor, some of it is treated with chemicals. Other fungicides typically are not used.

Cultural practices for disease control in soybeans, such as crop rotation, usually come as a by-product rather than as a specific objective. Usually, fewer acres of soybeans than of corn are grown on Corn Belt farms. Corn and soybeans form the typical rotation. In some areas, winter wheat and soybeans conveniently fit together in a rotation. Hence, soybeans are rarely planted continuously or even for several consecutive years on the same piece of land. As a result, the causal agents of many of the soybean leaf diseases that may survive from season to season in soybean refuse are destroyed. Brown stem rot, a soilborne disease, is substantially reduced in fields that have one or two seasons in another nonhost crop.

A few disease-producing agents are seed-borne. Generally speaking, seed from badly infested plants fails to meet normal certification standards or is otherwise rejected for seed usage.

Selection against disease susceptibility is practiced during varietal development in breeding programs. Active breeding programs with disease resistance as the primary objective have been carried out for a few diseases, such as bacterial pustule, phytophthora rot, frogeye leaf spot, and cyst nematode. As a result of these breeding efforts, disease rarely has become a limiting factor for soybean production in the Corn Belt.

PEST CONTROL IN STORAGE AND TRANSIT--CORN, SOYBEANS

Although not the primary source of interest in the pest control field and not the center of attention in this report, pest control problems that occur after harvest are of some importance. Since both corn and soybeans are capable of being stored at fairly low cost for long periods of time and since they often move long distances between production and consumption locations, pest problems in storage and transit do occur. The primary ones involve insects, fungi, and rodents.

Corn and soybeans in storage and in transit are obviously not in their natural growing environment; they are in a man-made environment. Consequently, careful control of this environment is the most useful and least costly pest control method available. Pest control in this more-or-less controlled environment depends primarily on the regulation of humidity, temperature, and access. The main control for storage diseases like molds and rots is to dry the corn or soybeans to 12 percent or less moisture or to hold these products at temperatures below 35 F. For commercial purposes, drying is by far the most economical and widely used method of disease control. Preservatives such as propionic acid can be added to wet corn held in storage for animal feed.

Although dependable detection is difficult, corn grain and soybean products can be tested for aflatoxin content by flourometric methods. Lots with more than allowable limits are rejected for food or feed. Aflatoxins are injurious compounds produced by certain fungi growing on maturing or stored seeds and grain. The only known control is to prevent these fungi from growing. There are no known ways of feasibly removing or inactivating aflatoxins once they are produced in a plant product.

Control of temperature and humidity of corn and soybeans in storage for disease prevention also retards insect infestations as does general sanitation in and around storage areas.

Control of access for rodents and insects is accomplished in the United States primarily by means of metal and concrete storage bins and structures. Truck, water, and rail shipments of grain are typically made in enclosed trailers, barges, hopper cars, and boxcars, with fairly careful attention to possible contamination by water, chemicals, insects, and rodents. However, applications of fungicides, insecticides, and other chemical agents are not routinely practiced on corn and soybeans in storage or in transit.

PEST CONTROL IN CORN AND SOYBEAN SEED PRODUCTION

In most respects, production practices for corn and soybean seed are parallel to those used on commercial grain farms, hence, pest problems are similar. However, production practices are typically followed with more care and more skill on seed-producing farms than elsewhere.

The per unit value of the seed crop is much higher than that of commercial corn or soybeans. Hence, it is economical to use additional and more costly methods to protect the seed crop against weeds, insects, and plant diseases. Such protection results in higher-quality seed.

Seed Corn

The use of hybrid corn seed is vital for obtaining high yields. In contrast to soybeans, farmers typically purchase new seed each year, because seed harvested from their own fields of hybrid corn (F_2 generation) generally will yield 15-20 percent less than new hybrid seed (F_1 generation). New hybrid seed corn is produced annually by commercial seed companies. To reduce risk of crop failure, seed companies select highly productive fields for seed production, follow good fertilizer programs, and use herbicides and insecticides.

Weed control in hybrid seed corn fields is essential. The inbred lines used in making single crosses lack the vigor of hybrids. They are shorter and grow more slowly; therefore, they compete poorly with weeds. Without effective control of weeds, there would be little seed production from corn inbreds. Hybrid seed corn producers select fields to avoid heavy weed infestations or infestations of weeds that are difficult to control.

Inbred lines tend to be more seriously affected by herbicides than are hybrids. Hybrid seed corn producers use new herbicides with a great degree of caution and avoid large-scale usage until they are certain that their inbreds and hybrids will tolerate them. Atrazine, propachlor, and alachlor are considered safe enough to use on corn inbreds by many of the hybrid seed corn producers, but there are label restrictions on the use of dicamba and dalapon and 2,4-D. There is some evidence that dalapon accumulates in the seed and affects germination. In a few instances, dicamba and 2,4-D, when applied late, have affected seed set and have resulted in barren cobs. These instances have been relatively rare but make seed corn producers reluctant to use these compounds.

Insect control in seed corn fields is quite similar to that for commercial grain production. Inbred corn lines are often more susceptible to insect damage than hybrids. Hence, more spraying generally is practiced in seed fields.

Corn disease control in the production and distribution of seed is similar to that for the commercial crop, except that direct applications of fungicides to control leaf diseases are sometimes used in seed fields. One of the inbred lines used to produce a given hybrid line may be susceptible to disease and can sustain loss in yield and quality. Disease susceptibility of an inbred parent may be masked by the resistance of the other inbred parent, so the final hybrid grown by the farmer is satisfactorily resistant.

In some instances, an insecticide is used to control an insect that carries a disease-producing organism to the corn crop. For example, the causal bacterium for Stewarts bacterial wilt and leaf blight is carried by the corn flea beetle. The bacterium enters the corn plant through feeding injuries of this insect.

Often seed corn ears are individually hand-sorted, and nearly all are dried with supplemental heat. All seed lots are carefully tested by the seed firms for germination and seed quality. Unsatisfactory lots are rejected for sale.

Soybean Seed

Soybeans are a self-pollinated crop. Varieties planted by farmers are essentially inbred, true breeding lines. Seed harvested by a farmer, therefore, can be replanted without any systematic loss in yield. Because of this, every acre planted by the farmer is a potential acre of seed for the following year. This reduces the vulnerability of the soybean seed supply to local or regional production problems or pest problems. Some lots of seed are produced by farmers under contract to seedsmen. The pest control procedures are, therefore, quite similar in both the seed and the commercial crop.

ECONOMIC ASPECTS OF PEST CONTROL

The economic aspects of pest control in agriculture have much in common with the economics of technology and technological change. In considering these issues, there are at least three levels of discussion and analysis. The first focuses on the direct economic and technical questions of pest control from the viewpoint of the individual producer. Here, the major problems involve application "thresholds" and timing, the optimal rate of application, the selection of products and strategies for maximum returns, and the effects of uncertainty as it relates to "insurance" rates of application.

The second level of discussion involves direct costs and returns from the marketwide point of view. Here, questions such as the effects of pest control on prices and aggregate production are pertinent. Issues of product variety, quality, and storage also are relevant. The location of production and implications for regional specialization may be involved. On the other side of the market, the economic structure and behavior of the pesticide industry could be considered. Prices, output, and product quality, as well as effects of regulation, research, and innovations in the industry, are relevant.

Third, and quite important, are the indirect or external effects of pest control that are experienced by society but not reflected by traditional market mechanisms. These externalities, or "side effects," may be experienced on the farms or in regions where production and pest control occur, or they may be diffused widely over time, through the society, and in the environment. They can involve such diverse problems as toxic buildup in the environment and changes in rural society.

Each of the three main economic questions mentioned above are considered in the following sections, although not in detail. Research data are available on some issues; and others, such as the market structure and behavior of the chemical pesticide industry, clearly transcend the corn and soybean sector and the scope of this report.

Direct Costs and Results of Pest Control to Producers

The previous sections in this chapter have focused on the physical and biological aspects of pest control methods now commonly in use in the corn/soybean sector. In this section, we will consider some of the microeconomic aspects of the control of major pests in the Corn Belt. The goal is not to present and discuss thoroughly the extensive data that do exist, but rather to summarize and highlight the key relationships that emerge from the data and from previous research in this field.

Much of the information that is now available on costs and returns from pest control comes from past and ongoing studies by the U.S. Department of Agriculture and by economists and others in land grant universities. A recent private study done for the Commission on Environmental Quality summarizes much of this work as it pertains to the Corn Belt and adds additional information (von Rumker and Horay 1974). This latter effort parallels, in some ways, the work of this corn/soybean study team.

For practical purposes, the *direct* costs of pest control in this sector involve insecticides and herbicides applied on corn and herbicides applied on soybeans. Very few insecticides are used regularly on soybeans, and almost no fungicides are applied directly to either crop. Table 3-6 illustrates this point for the years in which USDA data are available.

TABLE 3-6 Pesticide Application Data for the Corn Belt, 1964, 1966, 1971

Item	Million Pounds of Active Ingredients Used in the Corn Belt[a]		
	1964	1966	1971
Corn			
Insecticides	10.8	17.5	15.3
Herbicides	12.6	27.5	54.1
Fungicides	0.1	negl.	negl.
Soybeans			
Insecticides	0.5	0.2	0.1
Herbicides	3.0	6.6	18.9
Fungicides	0.2	negl.	negl.
Other crops			
Insecticides	3.0	3.7	3.0
Herbicides	1.4	1.4	3.4
Fungicides	7.9	5.4	5.3
Total			
Insecticides	14.3	21.4	18.4
Herbicides	17.0	35.5	76.4
Fungicides	8.2	5.4	5.3

SOURCE: USDA.

[a] Illinois, Indiana, Iowa, Missouri, and Ohio.

It is difficult to assess direct costs to farmers of plant disease control through resistant varieties. Although seed prices for resistant varieties may be higher than they otherwise would be and producers in practice can exercise some choice among varieties, the basic research in genetic resistance traditionally has been done by public institutions. Some seed costs probably should be charged to pest control, but the basis for doing so would involve analyses beyond the scope of this report.

Although questions have been raised about the absolute level of the data in Table 3-6, the relative amounts and trends involved seem to be accurate. While insecticide applications on corn seem to have leveled off, the use of herbicides in corn and soybeans has increased fourfold and sixfold, respectively, since 1966. In total, herbicide use in 1971 was 4.5 times its 1966 level. Insecticide use in the sector increased about 28 percent from 1964 to 1966, then declined about 14 percent by 1971. Table 3-7 provides some data on the major compounds used.

From the individual grower's point of view, pesticide application on corn and soybeans has three main economic characteristics: (1) it is a moderately small cost item in production, (2) it is quite productive compared to other inputs, and (3) it can prevent large unexpected losses in output. Let us consider each of these in turn and then look at the concept of economic threshold in pest control.

Pesticide Costs

The available data on farm expenses suggest that pesticide costs have not been a large component in the total production cost picture. Without presenting all the data and analyzing its comparability, it appears that pesticide costs on Corn Belt corn represent about 15 percent of variable costs per acre and about 6 percent of total costs. Similar figures for soybeans suggest that pesticide (mainly herbicide) costs are of a similar order of magnitude, representing about 18 percent of variable costs per acre and about 6 percent of total costs. Compare this to fertilizer, which accounts for about 34 percent of variable costs in corn and 23 percent of variable soybean costs.

Another way to look at pesticide costs is to compare pesticide application to the value of the product upon which it is used. Tables 3-8 and 3-9, which are based on USDA data, provide such a comparison for corn and soybeans. Although these comparisons must be used with caution, it

TABLE 3-7 Pesticide Application Data, by Major Compounds, United States, 1971

Item	Million Pounds of Active Ingredients	Percent of Total
Corn Insecticides		
Aldrin	7.7	28.2
Carbamate group	3.8	13.9
Phorate	2.7	9.9
Carbofuran	2.7	9.9
Diazinon	2.0	7.3
Carbaryl	1.6	5.9
Parathion	1.3	4.8
Heptachlor	1.1	4.0
Others	4.4	16.1
TOTAL	27.3	100.0
Corn Herbicides		
Atrazine	52.0	51.5
Propachlor	21.3	21.1
2,4-D	9.0	8.9
Alachlor	8.4	8.3
Butylate	5.8	5.7
Others	4.5	4.4
TOTAL	101.0	100.0
Soybean Insecticides		
Methyl Parathion	2.2	38.6
Toxaphene	1.5	26.3
Carbaryl	1.3	22.8
Others	0.7	12.3
TOTAL	5.7	100.0
Soybean Herbicides		
Chloramben	9.2	24.7
Alachlor	6.3	16.9
Trifluralin	6.0	16.1
Dinitro group	3.6	9.6
Maptalam	2.9	7.8
Nitralin	2.1	5.6
Vernolate	1.4	3.8
Flurodifen	1.2	3.2
Amitrole	1.0	2.7
Others	3.6	9.6
TOTAL	37.3	100.0

SOURCE: USDA.

TABLE 3-8 The Value of Corn and Soybeans Compared to Herbicide Costs, 1971

Item	Average Value of Crop Per Pound of Herbicide Applied	Approximate Average Cost Per Pound of Herbicide Applied (Active Ingredients)
Corn	$54	$3.25
Soybeans	$95	$5.00

SOURCE: USDA.

TABLE 3-9 The Value of Corn and Soybeans Compared to Insecticide Costs, 1971

Item	Average Value of Crop Per Pound of Insecticide Applied	Approximate Average Cost Per Pound of Insecticide Applied (Active Ingredients)
Corn	$223	$1.60
Soybeans	$620	$1.25

SOURCE: USDA.

is clear that, in the aggregate, the cost of pesticides is a relatively small part of the total value of both corn and soybeans. Even with the rapid, recent inflation in virtually all costs and prices in the farm sector, it appears from other USDA data that pesticide prices have risen less rapidly than the overall index of prices paid by farmers for production items.

Profitability

Pesticides are, from the grower's point of view, an input that really pays off in application. This assertion can be supported in several ways. J. C. Headley (1965) investigated the aggregate productivity of pesticides in U.S. agriculture. He estimated that for each additional dollar spent on pesticides (in 1963), the returns were about $4.

This marginal product was higher than that for all other classes of inputs, except fertilizer. This is only a rough approximation and is based on aggregated data, but it does suggest that, for the nation's agriculture as a whole, pesticide use was highly profitable at the 1963 level of application. Similar national estimates for 1969 by Shatava (1971) run as high as $5.70 for each additional pesticide dollar. They reach approximately $6.80 in the Corn Belt. In this study also, pesticides were rivaled only by fertilizer in their marginal production values for large aggregates of producers.

Other studies show clearly that both insecticides and herbicides, properly applied, typically increase per acre yields substantially when compared to untreated areas. (With herbicides these comparisons are perhaps more complex, since mechanical cultivation is still a feasible alternative.) When average prices of the products and the pesticides are considered, the impression is strengthened that insect and weed control are economically attractive to the farmer. This must be so, since R. von Rumker's recent survey indicates that more than 98 percent of moderately large corn and soybean growers in Iowa and Illinois used herbicides in 1973 and about 60 percent of corn growers used insecticides. Other estimates cited in that study indicate that in 1973 some 80 percent of all Corn Belt corn acreage and 75 percent of soybean acreage were treated with herbicides. Approximately 50-60 percent of the Corn Belt corn acreage was actually treated with insecticides in 1973. Presumably, substantially more growers are prepared to apply insect control if outbreaks occur either in their own fields or nearby.

In the same survey of corn and soybean growers, respondents were asked if they would alter pesticide applications if the costs were twice as high as they actually paid. In all cases, a majority of growers said they would not change their use patterns. This strongly supports the view that, with current prices and production relations, pesticide use is quite profitable both on the average and at the decision-making margin. In particular, if pesticide prices doubled, about 60 percent of Iowa and Illinois growers would not alter corn herbicide use; about 70 percent would not change herbicide use on soybeans; and about 70 percent would not change insecticide applications on corn.

In this same study, R. von Rumker has brought together a variety of partial budgeting studies to evaluate the profitability of chemical insect and weed control in corn and soybeans. Although the various studies and the data used are rather specific as to time, place, treatment, and effects, the general impression is that chemical insect and weed control in the corn/soybean sector are clearly profitable production techniques. This adds support to the general conclusions that emerge from statistical productivity studies, cost data, and farmer interviews.

Insurance Treatments

Aside from being profitable, low-cost inputs, pesticides also can be used as a form of insurance against the uncertainties of unexpected pest outbreaks. This insurance function is a much-debated subject and applies mainly to insecticide use, though aspects of it appear in herbicide weed control and, to a lesser extent, in plant disease control.

There is some agreement that perhaps 50-60 percent of the corn acreage treated with insecticides in the Corn Belt annually represents unneeded application--unneeded, that is, in hindsight. In the early stages of each growing season, it is difficult for growers to predict whether treatment is going to be needed on a given field or farm. Recommendations from the extension services and the private trade often vary, and nontreatment can be financially disastrous in a pest outbreak. Therefore, since pesticides do not harm the crop directly, since they are cheap in relation to crop value, and since information is imperfect, the theory of production economics and common sense both suggest that insurance-type applications will be made by prudent growers, even though they are clearly a misuse of insecticides from the broader perspective.

In the context of a single growing season, the pure insurance application represents to the grower an increased cost, which may or may not be recovered that year in increased output. Yet, because it reduces some of the uncertainty associated with corn and soybean production, such applications can increase the expected value of net farm income over several years when the probability and uncertainty of pest attack is considered. It is also in the longer-run that other costs, both direct and indirect, are sustained by growers and by society at large. These costs are important, although difficult to evaluate, and will be discussed in a later section.

Economic Threshold

The concept of the economic threshold is an elusive one. It is used mostly in connection with *insect* control strategies in agricultural crops; but like insurance applications, it is also relevant to weed and disease control. The overall objective of any notion of economic threshold is to add selectivity and sophistication to pest control activities. The result sought is the reduction of unneeded "insurance" applications of chemicals and the most effective use of those that are applied. Direct economic benefits to the individual grower, reduction of insect resistance, avoidance of toxic buildup in the environment, and minimal effects on nontarget species all can result from more careful insecticide application strategies. The notion of an economic threshold is, therefore, at the core of most pest management concepts and strategies now being developed.

Generally speaking, the economic threshold is the point of pest infestation at which purposive control steps should be taken. A sizeable number of formal and informal definitions and descriptions of the economic threshold are found in the literature and are used in research or extension recommendations. They range from conceptually quite vague to quite rigorous. More elaborate notions of the threshold attempt to identify economically "optimal" levels of the pest population to be tolerated by producers at given costs of control and prices of output. All notions of the economic threshold involve principles of biology and economics at various levels of sophistication.

The original approach to identifying the economic threshold was developed mainly by economic entomologists. This approach is well advanced in practical application and, in one way or another, forms the basis for most extension recommendations on insecticide applications in the corn/soybean sector. It is fairly simple in its economic principles but can be quite sophisticated in its biological aspects. The central idea is to first predict the potential level of damage inflicted by insects, based on early and repeated population estimates or counts in the field. Then the insects are controlled by chemical measures when the potential damage (yield loss) avoided is equal to or greater than the cost of a single treatment. The economic threshold is the population of insects in the field, which, if left unchecked, would ultimately cause damage equal in value to the treatment cost. The latter level of crop damage is called the "economic injury level."

Treatment costs are viewed as a fixed amount per acre, and the decision is "treat" or "not treat." In economic terms, this is a break-even strategy with respect to pest control. It is a strategy to avoid loss and permits profit maximization to occur on the balanced application of all other inputs. However, the biological relationships between sequential insect counts, population dynamics, plant damage, and yield loss may be and often are complex. Yet, the critical point at which control is applied depends not only on the biological parameters of insect behavior and damage potential but also upon the prices of outputs and the costs of treatment.

Some newer approaches to the threshold question utilize more complex economic and statistical principles and require as much or even more biological sophistication as do the current practices. The central issue is "how much" treatment is to be applied. Therefore, the new approaches involve an optimizing management strategy rather than identifying break-even points. The central idea is to identify, during the growing season, insect population levels at which overall net returns or profit are maximized and then design control measures to hold the population at those levels. The insect population is viewed as a controllable variable with control costs negatively related to the population level maintained within the dynamic context of the growing season.

The economic threshold at a given time, in this more complex formulation, is the population level at which the additional costs of more control are just balanced by the potential revenue gains associated with the added control. A lower level of infestation would cost more to control than it would yield in revenue. A larger permitted level of infestation would decrease costs less than the associated fall in revenue. Elaborations of these ideas to include complex questions of timing and uncertainty have been made and are currently under investigation. This latter approach requires as much technical and biological information as the traditional approach and surely requires more complex cost and revenue considerations. But since it does view the pest population as a control variable subject to optimizing criteria, it could become a central principle of sophisticated future pest management strategies.

These two approaches to the economic threshold concept are noncomparable in some important respects. While both view revenue as a declining function with respect to increased pest levels, there is a quite different view of the cost relations and the extent to which the pest population is subject to close management by the crop producer.

At present, the original economic threshold concept is operational and is being widely applied in the corn/soybean sector, at least for extension service recommendations. The more complex concepts seem to be a long way from being useable in actual practice. Based on the current state of development of the ideas and the estimates of costs available, it does not seem possible to assert now that either view of the economic threshold necessarily would lead to lower chemical applications than the other in the short or long run. However, more widespread use by growers of either threshold formulation would reduce insurance applications of insecticides and thereby reduce the overall toxic load in the corn/soybean sector.

Some fragmentary evidence from Florida on soybeans suggests that threshold applications of insecticides based on scouting reports in a region may be cheaper than routine applications based on calendar dates during the growing season, even with constant yields in both cases (Greene 1974). On a per acre basis, the conventional system entails estimated costs of $11 per acre, while the cost of the pest management system, including scouting costs, is estimated to be $7.

Conceptually, the notions of economic threshold also are applicable to weeds and plant disease, although the weed and disease pest problems have not been formulated in this way. The preemergence application of herbicides, for example, could be viewed as an insurance practice to some extent. Since weeds are not sporadic or epidemic in their occurrence in the Corn Belt, the preemergence herbicide treatment, which could be avoided with early season weed seed counts, would likely be rare, given current technology and weed abundance in the sector.

Weed Control

In the Corn Belt, weeds are a constantly present, nonsporadic pest problem. Data on actual occurrence and counts of weed seeds present in soils indicate that weed control, in some form, in the corn/soybean sector is continuously required.

Weed control is most effective when undertaken before the magnitude of the problem is fully evident in any particular growing season, e.g., preemergence treatments. Moreover, chemical weed control, unlike chemical insect control, is a substitution of an effective alternative technology for well-known mechanical control methods. In addition, herbicides can be used in combination with mechanical weed control or as a complete substitute for it. Almost all commercial corn and soybean growers in Illinois and Iowa included in von Rumker's 1973 survey used herbicides (von Rumker and Horay 1974). This suggests that herbicides are, in fact a partial or complete substitute for mechanical cultivation over a wide range of conditions. The virtual explosion in the use of herbicides on corn and soybeans since 1966 confirms this view.

The machinery requirements for mechanical weed control in corn and soybeans are not complex or expensive compared, for example, to harvesting equipment; and they are even less complex than machine requirements for herbicide application. Therefore, the main economic goal in applying herbicides is to achieve weed control using less labor and time than with mechanical cultivation. In fact, the traditional patterns of mechanical weed control generally provide less-effective weed control than widely used combinations of herbicides and mechanical cultivation or herbicides alone.

On balance, the use of herbicides lowers per acre costs of corn and soybeans and increases yields above those achieved with typical mechanical methods. Thus, net income is increased. Moreover, the labor requirements per acre are significantly reduced, enabling the operator to handle more corn and soybean acres or to engage in other crop, livestock, or off-farm enterprises.

Some recent experimental research results show that, along with higher average net income per acre, the year-to-year variability of income may be increased with the use of herbicides as compared to mechanical cultivation, all else being the same (Slife 1973b). Given the rates at which farmers have adopted herbicides in recent years, this increase in variation either has not been brought to the attention of farmers or it has been more than offset by the available gains in average income. Moreover, herbicides are only a part of the adopted technology that has affected yield and its variability on Corn Belt farms. For example, it is likely that the adoption of modern power and machinery, permitting more timely operations, has acted to reduce year-to-year variability. The development of drought-resistant varieties has had a similar effect. These effects may well have swamped any tendency toward increased income variability solely due to herbicide use.

Implications of Pest Control for Yield Increases and Yield Variability

Corn and soybean yields have increased substantially in the post-World War II period. A complex web of interrelated improvements has produced this development, including improvements in the genetic capacity of the commercial varieties, better machinery in all phases of production, more and better fertilizer, improved management, and improved control of pests.

Some research results mentioned earlier suggest that, next to fertilizer, pesticide applications (used as a measure of pest control) display the largest marginal productivities among all general classes of productive inputs to the extent that these can be measured. Because pesticides have a high measured productivity and since their application has increased substantially since World War II, it can be concluded that pest control in corn and soybeans is an important component of the upward yield trends in both crops. The data in Table 3-10 show the annual rates at which average corn and soybean yields

TABLE 3-10 Average Annual Rates of Increase in Corn and Soybean Yields for the Corn Belt States and the United States, 1946-1972

State	Average Annual Increase (bu/acre)[a] Corn Yields	Soybean Yields
	(bushels per acre)	
Illinois	+2.10	+0.44
Indiana	+1.98	+0.41
Iowa	+2.34	+0.53
Minnesota	+1.84	+0.30
Missouri	+1.96	+0.39
Nebraska	+2.72	+0.34
Ohio	+1.64	+0.34
United States	+2.29	+0.33

SOURCE: Basic yield data from the USDA.

[a] Computed from linear trend analysis.

increased in the Corn Belt states and for the United States as a whole between 1946 and 1972. Some but not all of this increase can be attributed to pest control efforts.

Naturally, pest control does not change the inherent productive capacity of the plant or its biological potential for using fertilizer, water, and other nutrients. It helps to control the productive environment, thereby allowing more of the inherent capacity of the plant to express itself in higher yields than otherwise would occur. Thus, the ability of pest control methods to increase output or to contribute to an increase is constrained by the upper level of the plant's potential output.

It has been hypothesized that improved pest control not only contributes to increased yield but also affects variability of yield about the average or the trend. The most common hypothesis in this connection is that successful pest control (especially insect and plant disease control) cuts down the sporadic forces that add variability to yields. This contributes to yield stability over time.

Control of weeds is a bit different. Weed infestations are not generally sporadic and are controllable to a large degree by mechanical cultivation. More effective weed control, by any means but specifically by herbicides, may allow the more natural variability of the species to emerge. It may be that the interaction between weather and herbicide effectiveness is more pronounced than the interaction between weather and mechanical weed control. The experimental data by Slife, discussed in the preceding section, provide some plausible results consistent with this view.

In actual practice, corn and soybean production involves several methods of pest control and a myriad of other forces that add to or suppress variability of yields. Is there any systematic tendency for yields of these crops to become more or less variable in actual practice as modern pest control has evolved? Again, we turn to the state yield data. The variability of yields about their linear trends was analyzed statistically to test whether or not variability was greater in the early or later portion of the period from 1946 to 1972.

Specifically, it was hypothesized that no change in yield variability had occurred during the period. The tests were designed to challenge this hypothesis to see if it could be overturned on well-accepted statistical grounds. The data in Table 3-11 summarize this investigation. There is no compelling evidence to suggest that yield variability of either corn or soybeans in the Corn Belt states has systematically changed one way or the

TABLE 3-11 Summary of Yield Variability Analyses for Corn and Soybeans in the Corn Belt and United States, 1946-1972

	Corn		Soybeans	
State	Apparent Change in Yield Variability	Outcome of Statistical Test[a]	Apparent Change in Yield Variability	Outcome of Statistical Test[a]
Illinois	Increase	Not significant	Decrease	Not significant
Indiana	Increase	Not significant	Increase	Not significant
Iowa	Decrease	Not significant	No change	--
Minnesota	Decrease	Not significant	Increase	Not significant
Missouri	Increase	Not significant	Decrease	Significant
Nebraska	Decrease	Not significant	Increase	Not significant
Ohio	Decrease	Not significant	Increase	Not significant
United States	Increase	Not significant	Decrease	Significant[b]

[a] At the 5 percent level of statistical significance. F-ratios of mean squared deviations from trend were used; the periods compared were 1946-1951 and 1967-1972.

[b] Significant at the 1 percent level.

other since World War II (Thompson 1966). Only for soybeans in Missouri can it be concluded that yields have declined in variability. Notice that for the nation as a whole, soybean yields are substantially less variable now than 25 or 30 years ago. Apparently offsetting developments among producing states caused this reduction in overall fluctuation. More powerful statistical analyses and more disaggregated yield data might throw added light on this topic. Yet, it seems unlikely that widely different results would emerge.

Direct Effects of Pest Control on Corn and Soybean Markets

Direct costs and benefits of pest control to individual producers or reasonably small groups of producers can be calculated with some accuracy. Experimental plot data (or even actual field experience) with and without pest control can be observed. Then returns and costs for various alternatives can be calculated at appropriate market prices for the output and costs involved. Net income or profit can be estimated and judgments rendered as to the most economical method or methods among the alternatives examined. These calculations may be simple or extremely complex, but in principle and in practice they are possible and highly useful. As indicated above, such calculations generally suggest that chemical insect and weed control are profitable in the corn/soybean sector.

On the other hand, no such direct or straightforward method exists for assessing the effects of pest control when a large segment of national corn or soybean production is aggregated. The results of individual profit and loss calculations in pest control cannot be aggregated across all producers in a market, even if regional differences in technical effectiveness and application methods are accounted for. The prices of the products and the costs of the inputs used depend upon the total level of production and/or the total amount of pesticides used. This phenomenon is characteristic of a market sector. Since we do not have experimental data for the whole economy, we cannot tell with precision what prices and costs would have been without the pest control actually used or what they might be under different pest control strategies.

For example, suppose we want to analyze the effects of chemical herbicides on soybeans in 1973. We do not know exactly what soybean yields and production would have been without herbicides, but our technical knowledge could give us a fairly reasonable estimate. However, the problem is further complicated; because without herbicide weed control, production probably would have been reduced, but this lower production would have generated a higher price in the market. The higher price would have offset some, all, or maybe even more than all of the loss of production. Consequently, gross income across the market and for individual soybean growers might have been lower, the same, or higher than with herbicides. In addition, without herbicides, production costs change, and *net* income can behave in unexpected ways for the sector as a whole and for individual producers. Typical marketwide profit and loss or benefit-cost calculations made, with average market prices, for given years may be inaccurate for many reasons, but especially because the prices used are subject to change. We cannot replay economic history under different conditions. Therefore, the prices and costs we apply to different situations are only estimates subject to sizeable margins of error. This is a traditional dilemma of economic analysis--especially economic policy analysis.

Moreover, benefits and costs of pest control are passed along to society in several ways that are not fully captured in farm-level profit and loss calculations. Through normal market channels, benefits of successful pest control are passed along to consumers in the form of lower prices, higher-quality products, and a more reliable supply. Increased volume moving through marketing and processing channels creates employment and generates other economic activity rather than being lost to pests. Indirect or external costs of pest control are passed along to society through their effects on the environment, nontarget species, and rural society.

Effects Through the Market

Since it is impossible to replay economic history, we cannot find out what the lack of pest control (or even more-effective control) in corn and soybeans would have done to prices and markets. Furthermore, it is beyond the scope of this report to provide an economic model sufficiently complex to estimate these effects. Such models do not now exist and other economic analyses dealing with the aggregate questions of pest control are fragmentary and focus on one or a few specific issues, such as the restricting of pesticide use either by crop or by chemical.

Some empirical results of several published and unpublished economic models are put together here to illustrate one way to view the marketwide effects of pest control in corn and soybeans. The empirical results discussed here are drawn from published and unpublished analyses of corn and soybean markets done by agricultural economists in the USDA and in some land grant universities (Houck *et al.* 1972, Meilke 1973, Matthews 1973, George and King 1971, Heien 1973). The analyses were not directed specifically to an assessment of pest control methods but can be used for that purpose. The results must not be viewed as precise calculations, but rather as illustrative approximations based on available research.

First consider the way in which the effects of an improvement in pest control effectiveness is felt in the market. Farmers adopt the technique because it promises to increase yields, reduce costs, release labor, or some combination of all three. The aggregate effect is for production to increase either because per acre yields are increased or because farmers can handle more acreage of the crop. (Of course, production-increasing effects will spill over into other enterprises mainly because of released labor, but that phenomenon is not specifically considered here though it is probably important.)

The increased production moves onto markets. The net effect is a downward pressure on prices. Other influences will often override and obscure the direct effects of improved pest control, but the pressure is there nonetheless. In corn markets, the downward pressure on price spreads through the livestock industry both here and abroad as feed becomes cheaper. Then the impact spreads to wholesale and retail meat and livestock product markets. Prices may not actually fall in these markets, because other price-increasing influences may continue to operate; but prices will be lower than if pest control improvements were not applied and production was accordingly smaller.

In the soybean market, increased volume puts downward pressure on soybean prices. This results in downward pressure on wholesale prices of soybean meal and oil in the United States and abroad. On the meal side, the main effects are similar in direction to those for corn, since feed and livestock prices are affected. On the other hand, lower soybean oil prices mainly influence the markets for margarine, shortening, and salad oils. In total, the effect of successful pest control generally spreads widely from the farming sector into the economy. Through the workings of international trade, the effects are carried to foreign buyers.

When pest control methods break down or are unable to contain the outbreak and spread of a pest in the corn/soybean sector, the economic results are essentially the opposite. Production falls and prices in the sector are subjected to upward pressures. In fact, sudden losses in production, due to changes in the pest situation, are more likely to occur than sudden increases, especially where insects or plant disease are concerned. On the other hand, improvements in pest control generally occur over a rather lengthy period of development and adoption. Hence, their economic effects are spread out over time.

Consider a 10 percent loss in the annual corn crop because of a specific or combination of pest problems. The figures in Table 3-12 indicate how this crop loss would affect some critical prices in the feed/livestock/meat economy (1) in the first marketing year after the loss

TABLE 3-12 Estimated Short-Run and Long-Run Price Effects of a 10 Percent Decrease in Corn Production Due to a Pest Control Problem in U.S. Agriculture

Item	Percent Change from Previous Year (Short Run)	Total Percentage Change after Full Adjustment (Long Run)
Corn price received by farmers	+10.2	+10.2[a]
Price of feed cattle	+ 2.6	+ 3.7
Retail price of beef	+ 2.0	+ 3.1
Farm price of pork	+ 0.8	+ 4.3
Retail price of pork	+ 0.5	+ 2.4
Wholesale price of broiler chickens	+ 2.9	+ 5.4
Retail price of broiler chickens	+ 2.2	+ 4.1
Farm price of turkey	+ 0.2	+ 5.7
Retail price of turkey	+ 0.1	+ 2.4
Retail price of eggs	+ 2.2	+ 3.6

[a] No production response to higher prices assumed.

occurred, and (2) in the long run after the feed/livestock/meat sector has fully adjusted to this reduced availability of grain. The tabular data illustrate the estimated *pure* effects of this isolated 10 percent drop in production. No changes in population, income production, or prices outside the sector are assumed. Only the supply situation changes but the demand situation is assumed to remain the same. All adjustments noted here involve a smaller supply being allocated across a constant demand framework.

Consider the short-run effects. According to the estimates of the economic models employed here, corn prices would rise to approximately offset the fall in production, leaving gross farm income from corn nearly unchanged. The higher farm prices for corn would lead directly to higher wholesale and retail prices for beef, pork, poultry, and eggs. Smaller spillover effects to other food and nonfood items would also occur. These short-run effects assume that production of other crops remains constant and that basic inventories of feeder cattle, hogs, chickens, and turkeys cannot be quickly changed.

Since the price effects in Table 3-12 are expressed in percentage terms, they are independent of measurement units and can be directly compared. Note that the relative magnitude of the price changes diminishes as the effects spread from the farmer toward the retail market. The effects of proportional changes in production can be easily evaluated by increasing or decreasing the figures in Table 3-12. However, as the assumed changes in supply become larger, the reliability of the results diminishes. Econometric models are rough approximations at best, and their ability to reflect changes in reality is strained the larger these changes are presumed to be.

The long-run effects also are shown. These effects assume that production remains decreased and the related corn price increase holds for an extended period of time with no change in the structure of demand. The idea here is to rule out subsequent increases in corn output in response to higher prices. We can then evaluate how increased corn prices are reflected in the livestock/meat sector only as adjustments in feeder cattle, hog, and poultry production occur. In all cases, the higher price of corn leads to production decreases in livestock and meat and to larger price increases in these products in the long run as compared with the short run. These long-run effects are especially dramatic in the pork and poultry sectors where corn is the predominant feedstuff. Any output response to the higher corn prices would tend to moderate the longer-run price impacts of the initial production decline.

The figures in Table 3-13 indicate how a 10 percent fall in soybean production would affect some critical prices in the economy, to the extent that these are measurable. In the short run, soybean prices at the farm level would increase to almost offset the production decline. Prices of soybean meal and oil, the joint products of soybean processing, also would increase in response to shorter supplies. However, because the demands for these products are independent and fundamentally different from each other and because meal and oil occur in different proportions in the raw product, the percentage changes in meal and oil prices differ greatly. A large, relative short-run change (+15 percent) occurs in oil prices, but a rather small (+5 percent) change occurs in meal prices. The meal price change is distributed widely through the meat economy. However, the available research results do not provide as clear a picture of price changes throughout the livestock/meat sector in response to changes in soybean production as they do with corn. The smaller relative price change in meal is the main problem in this case. However, the soybean oil price change spreads dramatically into the fats and oils sector as indicated. Again, the indirect spillover effects into other markets are not shown.

The long-run effects are computed in the same fashion as with corn. The soybean meal and oil price increases are assumed to hold for an extended time to assess their impact over the long run. Soybean meal price increases affect livestock production and prices to a larger extent in the long run as compared with the short run. However, the long-run impacts do not differ from those of the short run as much as with corn. Higher prices for soy protein tend to choke off production increases in cattle, hogs, and poultry. With no increase in soybean production allowed in response to higher prices, the short-run increases in prices of products using soybeans are sustained into the long run. Any output response would moderate these long-run results.

The coefficients in Table 3-12 and 3-13 can be used in reverse with negative signs to evaluate the approximate effects, in terms of lower prices, of *successful* pest control efforts. The long-run effects, which allow for the passage of several years, probably are most appropriate in this particular connection.

To repeat, it is impossible to know what the agriculture economy and food prices would look like now if modern pest control technologies had not been employed. But the price impacts caused by changes in the corn/soybean pest control

TABLE 3-13 Estimated Short-Run and Long-Run Price Effects of a 10 Percent Decrease in Soybean Production Due to a Pest Control Problem in U.S. Agriculture

Item	Percent Change from Previous Year (Short Run)	Total Percentage Change after Full Adjustment (Long Run)
Soybean prices received by farmers	+ 9.6	+ 9.6[a]
Soybean meal price at wholesale	+ 5.0	+ 5.0[a]
Soybean oil price at wholesale	+15.0	+15.0[a]
Retail price of beef	+ 0.2	+ 0.2
Farm price of pork	+ 0.5	+ 0.8
Retail price of pork	+ 0.4	+ 0.5
Wholesale price of broiler chickens	+ 1.6	+ 1.8
Retail price of chicken	+ 1.2	+ 1.3
Farm price of turkey	0.0	+ 1.7
Retail price of turkey	0.0	+ 0.8
Retail price of eggs	+ 0.4	+ 0.7
Retail price of margarine	+12.3	+12.3
Retail price of shortening	+21.0	+21.0
Retail price of salad oils	+14.3	+14.3

[a] No production response to higher prices is assumed.

situation can be examined, at least approximately, with the help of economic research. These estimates suggest that the benefits of pest control and the costs of pest outbreaks are not confined to the farm sector. In fact, taking the corn and soybean sector *in the aggregate*, pest problems may be approximately neutral in their short-run effects of aggregate farm income as prices elsewhere in the economy respond. Of course, the income of individual producers suffering higher-than-average losses would be hurt. Even some operators suffering average or lower-than-average losses might be badly hurt by these losses. It is plausible to suggest that large, heavily capitalized firms depending upon sophisticated, modern, pest control methods may be more economically vulnerable to economic reverses than smaller, less-sophisticated operations. The differential effects of pest control problems come not only from unevenness in the actual damages from uncontrolled pest outbreaks, but also in the unevenness of farm size, farm management ability, and farm financial structure.

It is possible that the estimates contained in this section may somewhat underestimate the effects of production changes on prices in the corn/soybean sector, especially in the present situation. During the period over which the estimates were generated, reserve stocks of grain (especially corn) in public and private inventories were generally larger relative to production than they are now or will be in the immediate future.

The costs and benefits of pest control spread themselves widely through the markets of the feed/livestock/meat sector and, where soybeans are involved, through the fats and oils sector. Since all the important products in this sector--corn, soybean, soybean meal, and soybean oil--are exported in large amounts, both the costs and benefits are shared by domestic and foreign users.

INDIRECT AND NONMARKET EFFECTS OF PEST CONTROL

In a market economy such as the United States, the physical flows of materials and services among the various participants (firms and individuals) are generally accompanied by reverse flows of money. Prices function to match these flows and equilibrate the system as changes occur.

There are some economic transfers among firms and individuals that are not accompanied by reverse flow of money. These are often called "externalities." Of particular interest is the benefit or damage experienced unintentionally or inadvertently by firms, consumers, and members of society at large through the application of pesticides. Use of a pesticide by one farmer may control his pest population but do so in a way that either benefits or damages neighboring farmers' crops. This effect usually is not taken into account by the individual farmer as he determines his "economic threshold" of application or the extent of his treatment.

The effect of pesticide use on nontarget species, both human and nonhuman, is also an example of an externality. This is because there are no institutional arrangements like markets to price and evaluate the effects of pesticide residues in soil, water, and food. Thus, these external costs or damages are not automatically reflected in private decisions. On the other hand, the beneficial uses of these substances in food production are more or less automatically valued by the markets for both the products (corn and soybeans) and the pesticide inputs.

Some of the external benefits and damages can be quantified and described. However, it is usually difficult to evaluate them in market terms, because no formal market exists for them. In addition, where there are both external costs and benefits, those who bear the damages may not be the same as those who obtain benefits. For policy evaluation it may be better to leave these quantities in their physical terms at least for purposes of discussion.

There appear to be five main classes of nonmarket externalities of primary importance in the corn/soybean sector: (1) spillover and drift of pesticides from users to nonusers; (2) carryover, persistence, and buildup in the environment of pesticide materials; (3) increased resistance of target species to the application of particular materials; (4) unplanned effects on nontarget species including predators of target species; and (5) effects on rural institutions. Each of these classes may contain both benefits and damages for society. However, most are not taken into account by commercial producers and distributors of pesticides or by farmers as they make day-to-day decisions. To some extent, spillover/drift and carryover/persistence/buildup must be considered by pesticide users and dealers respectively, since they may be held legally liable for obvious damages caused by negligence.

Spillover/Drift

This class of externalities occurs when pest control is applied to site A but some benefits or damages occur at sites B, C, D, and so on, in the same growing season. The latter may be located on the same or another farm, other private or public property. Wind-borne drift of herbicides or insecticides is perhaps the clearest and most commonly cited form of spillover/drift.

The complaint most often heard is that of spray drift onto susceptible plants. Spray drift of dicamba onto soybeans during the weed-control spraying of corn has been reported most often in the Corn Belt. In Minnesota, for instance, approximately one case of spray drift onto soybeans has been reported per 10,000 acres of corn sprayed with dicamba. Spray drift of 2,4-D onto soybeans is much less common, with one drift case reported per 100,000 acres of corn sprayed.

Clearly demonstrated environmental contamination through accidental drift from insecticide application appears minimal in the Corn Belt, although a few cases have been observed. Occasionally, nontarget beneficial insect species may be killed in a treated area or, through accidental drift, in an adjacent one. When it occurs across farm boundaries, it becomes an externality, because the original applicator is not directly affected, although he may be sued later. For example, bees that are foraging for honey production may suffer because of insecticide treatment by a corn or soybean grower who has no direct interest in the ownership of the bees or the returns from honey sales. However, when pesticides are applied for insect control in corn and soybeans and extension recommendations followed, then there is a minimal potential for environmental contamination that will have a long-term detrimental effect. There are legal means and precedents whereby parties injured by spillover/drift can sue the negligent applicator.

The commercial corn/soybean crops grown by farmers rarely receive a fungicide treatment in the field. Hence, the spillover or drift of toxic disease control chemicals to adjacent fields is minimal. These products, when used, are applied during the growing season when the crops adjacent to seed fields are not used for feed or food. In addition, the fungicides used on corn such as Zinc ion maneb, captan, and thiram have a low mammalian toxicity and break down to harmless products within 7 to 14 days following application.

Inadvertent or accidental poisoning of humans and animals coming into direct contact with pest control products might be classed as a spillover type of externality. Fortunately, there have not been many human health problems arising from the use of pesticide products on corn and soybeans. Most problems have come during mixing, loading, and filling operations at the time of application. Some accidental poisonings of children occur because of careless storage and handling of the toxic materials.

An important problem is the inadvertent poisoning of livestock. Most of these incidents occur because of improper storage and use of leftover products such as aldrin, dieldrin, heptachlor, and thimet. The national newspaper and television coverage of a recent dieldrin contamination of food of millions of chickens in Mississippi underscores this point. The recent, single loss of 900 cattle in Iowa because of a mistaken use of aldrin in their feed is another example. Spillover/drift, including accidental poisoning of humans and animals, can be reduced by restricting the application and handling of toxic pesticide material to trained and licensed applicators or by the improved education and training of private users.

Externalities of this type are important, but probably not controlling, factors in the selection of pest control strategies in corn and soybeans. Most can be described as accidents that, in principle, can be avoided by reasonably careful handling and use of pesticides. They are not systematic externalities in the same sense as, for example, increased resistance of target species.

Carryover, Persistence, and Buildup

It is most difficult to assess these externalities, since they are often not immediately evident or directly traceable to a single or particular event, and are usually of a long-range nature.

There is no current evidence suggesting the accumulation of herbicides in the environment or the food chain as a result of weed control in corn or soybeans. Atrazine, widely used in corn, occasionally persists from one season to the next under cool dry conditions or if recommended rates of application for the soil type are exceeded. This persistence makes it necessary for farmers to plant corn or a semi-tolerant crop the year following atrazine use or to avoid the use of atrazine on corn if an atrazine-sensitive crop is to be planted the following year.

In spite of widespread recognition by farmers that atrazine can carry over into the next growing season and injure susceptible crops, numerous instances of crop injury have been reported throughout the Corn Belt. Applications by growers in excess of label directions are usually to blame. With the recent introduction of shorter-residual herbicides such as procyazine and cyanazine, and with the use of alternative herbicide mixtures with short persistence, crop injury from atrazine carryover probably will decline.

Available evidence indicates that atrazine is not accumulating in the soil with repeated annual applications. Soil dissipation of atrazine is mainly by chemical and microbiological degradation with leaching and surface runoff being of little significance.

Persistence of insect control products in the environment is a much-discussed subject. Persistent chemicals may kill beneficial insects over a long period of time and may enter the tissue or affect the health of livestock that eat the affected grain or graze in the fields later. In general, the trend is away from the use of persistent chemicals in corn and soybeans. Persistent chemicals are sometimes defined as those that remain in the environment in active form for 1 year or longer. Current trends in federal and state regulations suggest that the persistent insecticides are rapidly being restricted for general farm use in the corn/soybean sector. Thus, the chlorinated hydrocarbons that tend to be persistent are being replaced by less-persistent organophosphate and carbamate-type compounds.

It should be recognized that there are positive as well as negative aspects of pesticidal persistence. Some level of persistence is imperative in order that any given pesticide be effective. For example, when controlling corn rootworm adults, one formulation of particular material has an effective life of 5 days. A slightly different formulation has an effective life of 3½ weeks. In order to achieve an equal level of control, one material would need to be applied five times vs. one application for the alternate material. With fuel shortages and high fuel prices and with regard to applicator hazard and environmental exposure, there is an obvious advantage to a single application. Thus, persistence should be viewed in perspective and balance. While long-term persistence and environmental buildup of toxic materials are important externalities, there is frequently good reason to use semipersistent materials. In addition, the replacement of persistent materials, such as aldrin, with nonpersistent materials, such as furadon, in pest control programs in the Corn Belt has frequently resulted in the use of a material with a higher mammalian toxicity. This increases the likelihood of accidental poisonings and toxic exposure.

The large amounts of the chlorinated hydrocarbon insecticides, aldrin and dieldrin, applied over the years to control corn soil insects, has resulted in measurable residues. Soybean plants absorb chlorinated hydrocarbons from the soil and store them in the bean seed. Their distribution among the various end products of soybeans has only recently come under study. The need was highlighted by a 1974 case in which a large number of chickens in Mississippi were found to contain unacceptable levels of dieldrin. Some evidence also suggests that these chemical agents may pose a cancer risk to man.

About 60 million pounds of chlorinated hydrocarbon insecticides were applied in one state, Illinois, from 1953 to 1973. However, by 1974 annual usage in Illinois had declined 80 percent from its 1967 peak. In addition, the Environmental Protection Agency has banned further manufacture of aldrin and dieldrin for agricultural purposes after present stocks are used up. But residues remain from previous treatments.

Aldrin largely disappears within 1 year after application, but about 25 percent shows up as dieldrin, a compound with about a 4-year half-life. Based upon that half-life, the calculated amount of chlorinated hydrocarbon insecticides and metabolites in Illinois soils from fresh applications plus residues were as follows:

1960	0.2 lb per acre
1965	1.0 lb per acre
1970	1.6 lb per acre
1973	1.4 lb per acre

These data are only approximate, because no adjustment was made for differences in half-life of dieldrin vs. heptachlor epoxide and chlordane. There were, of course, individual fields with much higher residues. If no further applications are made following 1974, the residues will decline to 1.0 in 1975 and to 0.5 in 1980.

Available information suggests that much of the chlorinated hydrocarbon residue is concentrated in material that usually is used for nonfood purposes. Due to unusually high feed prices in 1973-1974, some of the material intended for industrial use was diverted into livestock feed, hence the incident of contaminated chickens.

Resistance of Target Species

There is little evidence of the development of weed strains in the Corn Belt tolerant to the herbicides that have been used extensively. Two herbicides, 2,4-D and atrazine, have been used extensively for 15-25 years. Some people believe that Canada thistle is now somewhat more tolerant to 2,4-D than it used to be; however, it still gives adequate control of Canada thistle in corn. There are reports that an atrazine-resistant strain of redroot pigweed has been found in Washington State (Thompson *et al.* 1974). Resistance of this nature has not been discovered in the Corn Belt.

There have been shifts in weed species in the Corn Belt that can be attributed to the use of herbicides. An increase in annual grassy weeds is attributed to the extensive use of 2,4-D during the 1950s. This herbicide compound reduced broadleaf weed competition markedly in row crops and may have allowed the 2,4-D tolerant grasses to flourish. Extensive use of atrazine also is believed to be responsible for similar changes in species frequencies. Atrazine-tolerant species such as crabgrass, fall panicum, and witchgrass have increased while atrazine-susceptible species have declined. Fortunately, there is a wide range of herbicides available, and most potential problems with this externality have been avoided until now. Control of nearly all of the major weeds in corn and soybeans is possible by choosing appropriate herbicides for specific weeds.

The tendency of some target species of insect pests in corn and soybeans to develop resistance to chemical insecticides is well known and well documented. The net potential increase in pesticide resistance of a target species is an external cost to any single producer making pest control decisions. The actual costs occur later in the form of increased dosages needed to control the more resistant pest and in the costs of development and distribution of newer effective chemical or nonchemical control methods. Moreover, when target species become resistant, the new insecticide that is developed is generally more expensive than the first.

Impact on Nontarget Species

When pesticides are applied to an agricultural crop, they have a direct effect on the physiology of the target organisms and perhaps on some nontarget species that are present at the time of application. A portion of these pesticides may then be distributed to untreated areas and species if treated organisms move or are consumed by predators, who in turn may be the food source for another species even if they were not directly in contact with the chemical. We know that:

1. Pesticides are highly toxic to some organisms. They are developed for their toxic effects on living systems and are applied at rates which are, in fact, toxic to the target pests.
2. Pesticides can affect a range of organisms. For example, some insecticides inhibit the activity of cholinesterase in the nervous system. They therefore attack a biochemical system that is universal in multicelled animals.

The potential dangers to an ecological system are of several kinds: threat to health of organisms, reduction of soil fertility, extinction of some wild species, inhibition of aquatic productivity, and reduction in the detoxifying capacity of the soil. The impact on a particular nontarget species within the system depends on the extent to which it relies on the food chain into which the pesticide is introduced.

In past years studies have been made of the toxicity of pesticides for many organisms. These studies may have underestimated the deleterious effects of chemicals for several reasons.

1. The studies were limited to direct lethal effects. Less-obvious effects of pesticides on reproduction, disease resistance, resistance to stress, and overall behavior were not usually studied. (However, more extensive tests over several reproductive generations are now required before a pesticide can be registered.)
2. Lethal effects often were evaluated with large single dosages. Constant exposure to sublethal dosages may have important effects. (Tests for chronic toxicity are now required in the evaluation of pesticides for registration.)
3. The physiological response to a pesticide varies with the age, sex, and general state of the exposed animals. In the past, laboratory and field studies typically used the most convenient and susceptible members of a population and may not adequately represent a natural population. Moreover, all relevant wild species may not be studied. (Tests including several generations and a larger number of relevant species are now required by the Environmental Protection Agency.)
4. Microenvironmental variation, even within a field, causes wide variation in effectiveness and can encourage

overapplication by growers as "insurance." (Recent law changes make misapplication by growers an illegal punishable offense.)

A great variety of pesticides are now being used. The joint effects of pairs of pesticides used together have not been investigated systematically. There are some instances of synergism. In particular, insecticides at very low sublethal doses can increase greatly the lethality of insect diseases. The ability of low concentrations to be indirectly lethal increases the potential for unintended consequences. It also opens up possibilities for increasing the specificity of pest control systems and reducing the required chemical dosages.

The harmful levels of pesticides, given by toxicity studies, should be compared to the actual levels of exposure occurring in the environment. This in turn depends on the rate of application, the pattern of distribution through the habitat, and the persistence of either the pesticide itself or its toxic derivatives. Table 3-14 illustrates the wide range of observed toxicity of important corn/soybean pesticide chemicals that have been reported in various studies. It is clear from this data that much remains to be learned about the toxic effects of these agricultural chemicals under differing conditions. About 10 percent of the pesticides used in the United States are applied to corn and soybeans. When applied at recommended rates, the amount of the chemical generally is several orders of magnitude below levels that show wide toxicity. However, all pesticides do not vanish within a year. While most pesticides used in the Corn Belt disappear in less than a year, atrazine may persist more than a year and aldrin and toxaphene may have half-lives of 2-4 years. The maximum accumulation of a pesticide lasting more than a year can be computed as: (annual application rate ÷ annual fractional loss) - (annual application rate). For example, an annual application rate of 10 lb per acre with an annual fractional loss of one-third would give a maximum accumulation of 20 lb per acre.

Pesticides are eventually destroyed by photolytic reactions; by chemical processes; and by the metabolic activity of animals, plants, and microorganisms. The rates of breakdown are sensitive to environmental conditions, varying with light exposure, soil moisture, organic matter, soil structure, and temperature.

Pesticides are also distributed unevenly by physical factors. Aerial and ground spraying make use of droplets of many sizes. Some of the smaller droplets may not reach

TABLE 3-14 Toxicity of Some Common Pesticides

Substance	Mammals (LD-50)[a] (mg/kg)[c]	Birds (LD-50) (mg/kg)	Fish (LC-50)[b] (ppm)	Amphibians (LC-50) (ppm)	Aquatic Arthropods (LC-50) (ppm)	Other Reported Effects
Diazinon	76-100	3-4	0.05-0.40	--	up to 0.8	
Aldrin	50	6-500	0.01-0.09	2.0	0.01-12	1 ppm reduces phytoplanton production
Parathion	4-14	1-200	<9.0	0.0004-.04		
Toxaphene	15-240	10-800	0.002-0.02	0.6-1.7	007-0.07	
Carbaryl	200-540	780->5,000	0.7-20	--	0.001-3	1 lb/acre produced 20 percent mortality in bees; 0.1 ppm toxic to algae; 21 lb/acre reduced litter decomposition
2,4-D	100-1,000	400->5,000	1-1,000	100	1-3,000	1-2 percent solution inhibits aerobic bacteria; 50 ppm inhibits soil nitrification
Atrazine	1,000-3,000	700->5,000	0.55-12		0.5-3.0	2-4 lb/acre reduced wireworms, earthworms and springtails; increases Azotobacter and nitrification

TABLE 3-14 (Continued)

Substance	Mammals (LD-50)[a] (mg/kg)[c]	Birds (LD-50) (mg/kg)	Fish (LC-50)[b] (ppm)	Amphibians (LC-50) (ppm)	Aquatic Arthropods (LC-50) (ppm)	Other Reported Effects
Trifluralin	>10,000	>2,000	0.1-.21	0.18	0.2-13	
Chloramben	>5,000					
Zineb	>5,000	>2,000				
Dieldrin	50-2,000	8-200	0.003-0.24	0.2-1.1	0.001-1.4	Toxic to soil bacteria, especially nitrifying spp.; 12 ppm reduced diatom production by 50 percent

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[a] LD-50 is the lethal dose taken internally which kills 50 percent of the animals, in most cases over a 24-hour period.

[b] LC-50 is the concentration in water which causes 50 percent mortality in (usually) 24 hours.

[c] The units of mg/kg are the same as ppm of body weight.

the target and can be distributed on a worldwide scale. For instance, DDT, derivatives of DDT, and dieldrin have been recovered at concentrations up to 0.16 ppm from the trade winds over the Atlantic. Samples of Cincinnati air in 1966 contained dust with 0.003 ppm of dieldrin. Distribution of pesticides in water is also uneven but widespread. Residues of several highly persistent pesticides have been recovered from all regions of the world, even the Antarctic.

The unevenness of distribution due to physical processes is increased on a smaller, local scale. Concentrations of persistent pesticides in the mud of lakes are usually three orders of magnitude greater than the water content of organochlorines. Aldrin can be concentrated 150-fold or more in algae compared to water and about fourfold in earthworms compared to the soil. The shorter-lived diazinon and parathion have been found in fish at 10-8 times the water concentration.

When a pesticide or any other outside influence acts on an ecosystem, its effect depends on the susceptibilities and position of individual species in the food network. Few studies have actually traced the interacting pathways, but the following consequences from pesticides that accumulate have either been observed or are plausible on theoretical grounds and should be looked for:

1. Nontarget species higher up in the food chain are more likely to be affected adversely than those lower down. This comes about for two very different reasons. First, a persistent pesticide may concentrate up the food chain. Secondly, predators may be killed by the pesticide or starved by reduced abundance of prey.
2. Among organisms on the same level of the food chain, species with long generation time (and large body size) would be affected more severely by cumulative pesticides.
3. Since pesticides are not applied to all areas, refuges exist in untreated areas. Therefore, the more mobile species and those with alternate hosts can repopulate from untreated areas and are likely to have a selective advantage over more sedentary and specialized species.
4. Within an ecological class, small differences in timing of the life cycle can be very important in differential responses of organisms. Therefore, competitive relations will be altered and the species composition of the community can change in ways that are unpredictable without detailed knowledge of the species.

5. Soil fertility is partly dependent on the degradation of organic matter by soil invertebrates and microflora. An inhibition of these processes can result in an apparent increase in organic matter. But lower *effective* levels of organic matter may result, requiring increased fertilizer applications. Toxaphene and carbaryl are toxic to algae at levels applied to crops. However, monitoring studies indicate toxaphene levels occur in water in the ppb range following normal agricultural use. This is too low to affect algae. Carbaryl applied at 2 pounds per acre can reduce litter decomposition by about 20 percent. Nitrification also is sensitive to pesticides. Usually aerobic bacteria are most sensitive. Atrazine has the atypical effect of increasing Azotobacter.

6. The soil flora plays an active role in the detoxification of the environment, breaking down not only pesticides but probably a wide variety of air pollutants including carbon monoxide. Here we are faced with a potentially dangerous positive feedback in which accumulating pesticides may reduce the detoxifying capacity of the soil and thereby increase the residual pesticide level.

7. There may be changes in the flora that are alternate hosts for predators (many parasitic wasps are nectar feeders). These flora are either affected directly or through the reduction of their pollinators.

8. The physiological effects of herbicides on plant growth may make the plants more susceptible to insects or diseases.

9. Insect species exposed to insecticides can build up resistance over a period of 2-10 years.

There are uncertainties about the toxicity, distribution, and ecological impact of particular pesticides. For example, the Environmental Protection Agency's recent ban on the use of aldrin in corn was based on its potential as a serious cancer risk to man. However, present levels of pesticide use in the Corn Belt are not known specifically to be dangerous to other nontarget species due to accumulation of the chemical at places far from the points of application. Yet the use of pesticides in the corn/soybean sector represents a significant part of the toxic load being added to the total environment.

Rural Institutions and Society

Virtually no manufacturer, distributor, or user of current pest control technology can be expected to consider the effects of his individual pest control decisions upon the rural economy or rural society. Yet, is it possible to identify external or nonmarket effects of modern pest control methods on the human institutions and the fabric of rural society?

There is no satisfactory way to disentangle pest control in the corn/soybean sector from the complex of chemical and biological technologies that have provided much of the upward thrust in agricultural productivity in the United States in recent decades. The core of technological change in U.S. agriculture has been to substitute mechanical, chemical, and biological inputs for labor with land use remaining approximately constant. These developments both have been caused by and have contributed to the massive outflow of population from farms and rural areas. As these population shifts have occurred, rural people and rural institutions have been subjected to great stresses (National Advisory Commission on Rural Poverty 1967). While no one could reasonably argue that pest control products or methods in corn and soybeans have alone caused these changes, they are an important part of a combination of technologies that contribute to the overall tendency for farms in the Corn Belt to become larger in size and sales, to employ less labor per unit of output, and to become more specialized and technically efficient.

To the extent that the decrease in numbers of people living and working in rural areas and the concentration of population in metropolitan areas is considered a social problem "external" to the efficient allocation of resources called for by markets, then technological change (and pest control as a part of this change) is at issue. If society decides to reinstate rural America as a growing source of employment, then public policy must deal with the state of modern agricultural technology. Society must somehow overcome (either by regulation or other incentives) technology's tendency to replace employment on farms and in rural areas with employment and unemployment in urban places. Much of this urban employment involves the production and distribution of agricultural inputs and the processing and marketing of farm outputs.) Such policies will not be easy to devise or inexpensive for the society at large. For example, policies to relocate industry into rural areas are now being pursued with mixed results.

People are both pushed and pulled out of rural society by the changes in the economy and in society. Many of the results are the same no matter what the cause. The major impacts involving (1) declining numbers of rural communities, (2) reductions in amounts and quality of rural social services, (3) disorganization of community life, and (4) social problems in urban centers are well documented and need not be recapitulated here. Specific externalities in this category involving pest control may be identified at least qualitatively.

Current pest control technologies are a part of a technological package and style of farming in the Corn Belt that can have important psychological implications for farmers and their families who stay in agriculture. For some, the necessity of constantly expanding and modernizing their farming operations is an exciting challenge. It is an ongoing and fascinating test of their skills and abilities. For others, there is the feeling of being on a treadmill, that they must keep advancing just to stay even. Many experience the nagging fear that one day they will lose out, and for many there is uncertainty about what to do if that happens. It is not known precisely what percentage of farm operators and their families experience these anxieties nor how severe they are. It does not take much visiting in rural Corn Belt communities, however, to verify that such anxieties do exist. Of course, these anxieties about the pace of change and uncertainties in modern life are not unique to agriculture; but since heavily capitalized owner-operator farms are common in the Corn Belt, these uncertainties are strong.

In a 1965 study by Beal *et al.* (1966), a random sample of 229 Iowa farmers responded to questions about agricultural chemicals and their use. The farmers were asked to say whether they agreed or disagreed with each of a series of statements about agricultural chemicals. The farmers were told that the statements were not necessarily true or false and that only their opinions were being sought. Although not explored by Beal *et al.*, the responses suggest that at least some farmers suffer dissonance (psychic tension or uneasiness) in using chemicals that they fear will have serious adverse environmental or other effects. While only 4 percent of them had *not* used any agricultural chemicals at all in 1964, 73 percent agreed with the statement, "present use of agricultural chemicals is polluting our rivers and destroying wildlife;" 36 percent agreed with the statement, "agricultural chemicals are the main cause of water pollution which kills fish;" and 44 percent agreed that "the use of agricultural chemicals upsets the balance of nature between soil, plants, animals and man." Undoubtedly, many farm people successfully reduce their dissonance by assuring themselves that the advantages of pesticide use outweigh the disadvantages. Indeed, in Beal's study, 80 percent of the farmers interviewed agreed that the wide use of agricultural chemicals has helped man to "stave off starvation and disease in many parts of the world," and 81 percent also agreed that "chemicals are an essential tool if the American farmer is to continue to produce good food at reasonable prices." Even though most consider the use of agricultural chemicals as a necessity, it is likely that some still worry and wonder whether they are doing the right thing.

An additional source of anxiety for some farmers, farm workers, farm supply dealers, and their families is the fear that they may be poisoned in the process of using or being exposed to pesticides. While the extent and severity of such anxiety in the Corn Belt is not known, its existence in California is indicated by efforts of farm workers' organizations to incorporate clauses on pesticide safety into labor contracts with growers.

THE DEVELOPMENT AND IMPLEMENTATION OF PEST CONTROL METHODS IN CORN AND SOYBEANS

The chemical and biological details involved in the discovery, development, and implementation of pest control methods are largely beyond the scope of this report. But the activities and interrelationships of the public and private institutions involved in the pest control field has a special bearing upon the processes and strategies of pest control in the United States.

Private firms, land grant universities, state and federal government agencies, private universities, and individual farmers all have roles to play in this field. To thoroughly discuss the interplay of forces within and among these agencies as they affect pest control in corn and soybeans in the Corn Belt would move quickly beyond this topic and embrace pest control in a wide variety of locations and cover a wide variety of pests. More importantly, perhaps, such a discussion would range far beyond pest control and confront an array of questions concerning the existing linkages among public and private institutions and their respective strengths and weaknesses. The specific issues involved in the interaction of farmers, private agribusiness firms, and the land grant system would be a major part of this discussion. The allocation and interplay of scientific research and other activities between state agricultural universities also would be an important focus of attention.

In this section, such a wide-ranging synthesis of ideas will not be attempted. However, as we look at the patterns of development of pest control products and methods some of these broader questions will be confronted and discussed to some extent. The first portion of this section will discuss the current role of various institutions in the pest control field. Then some broader comments will follow on the interactions and linkages among these institutions.

The Role of Private Firms

In general, the primary synthesis and initial testing of pesticides to control weeds, diseases, and insects is done by private companies. Once a product has shown effectiveness with regard to field performance against a pest in a major commodity, it is introduced to university and government scientists at experiment stations and extension services. These researchers, given the material on an experimental basis, field test it. If those tests are positive, it will go into additional large-scale field experiments sponsored by government and private firms. Labeling and registration efforts then will proceed.

The Federal Insecticide, Fungicide and Rodenticide Act, as amended in the 1972 Federal Environmental Protection Control Act (FEPCA), adds a new dimension to the pesticide situation. It provides authority for the regulation of pesticide application and use. If a pesticide is not labeled for a particular use, then it cannot legally be recommended and used for that pest problem. Before the FEPCA amendments of 1972, federal regulations provided for the registration of products, the establishment of efficacy, and the definition of permitted residues and tolerances. If research demonstrated that the pesticide controlled pest X, then it could be recommended for that use. However, under the current FEPCA (1972), the material must be *labeled* for use to control pest X before it can be recommended for that use. This places a constraint on pest control practices. This is especially important in view of the high costs for registering pesticides for specific uses. Several chemical companies estimate that it now costs 7-10 million dollars to register and market a new pesticide. With costs in this general range, companies primarily will proceed to register products for major market use. Registration may not be attempted for effective chemicals against pests of secondary importance, those occurring sporadically, or those affecting only minor commodities. Efforts to overcome this potential problem are under way through joint consultations involving the Cooperative State Research Service, the U.S. Department of Agriculture, the Environmental Protection Agency, and the land grant universities.

In addition to chemical control, the role of private firms extends to plant breeding for disease and insect resistance. Plant breeding of corn is a well-established private industry, while the interest of private firms in soybean breeding is just now developing.

The activities of private firms in the development of disease and insect resistance in their corn hybrids will vary from firm to firm. Smaller firms with limited staff simply observe their products in test plots and do not sell hybrids or varieties that display poor yield performance or show some obvious disease susceptibility. Larger firms with more technical staff may do extensive work. Some firms are able to make specific diagnoses of problems and to recognize weaknesses in their products. These larger firms also are able to select for disease and insect resistance and use these attributes as criteria in determining what hybrid to put into production and offer for sale. While some guidance may come from public researchers, most of the decisions relating to the usage of disease and insect resistance in the commercial corn crop are now made by private industry, since it determines which hybrids or varieties will be sold.

Land grant institutions and government agencies traditionally conduct most of the research that identifies sources of resistance and incorporates them into adapted genotypes. It is estimated that about 85 percent of all inbred germ plasm used for production of hybrid seed was initially developed and released from public institutions. Only a few large seed companies develop their own inbred lines from original parental sources, and these lines frequently are used in combination with publicly developed inbreds.

The production and commercial sale of hybrid seed corn is done exclusively by private companies. Almost all seed corn companies have a hybrid testing program to identify new combinations of inbreds that may be superior to existing combinations. Since all companies have access to public inbred lines, the same hybrid produced with two public inbreds may be sold by several companies under different brand names. Consequently, the large array of hybrids available to farmers does not reflect a corresponding amount of genetic diversity.

Until 1968, more than 98 percent of all variety development research in soybeans was conducted by public plant breeders. The increase in demand for soybean seed to plant an expanding acreage and the passage of the Plant Variety Protection Act in 1970 resulted in the formation of many private soybean breeding programs. By 1973, as much soybean variety development was done by private companies as by public institutions. In addition, the production of soybean seed for distribution to farmers is done exclusively by private seed companies.

The role of private soybean breeders in future variety development is not clear. Unlike hybrid corn, a soybean variety is the end product of the breeding program. Soybean varieties, in contrast to corn, require no further testing of inbreds in hybrid combinations. Private breeders will continue to develop new varieties. The role of the public breeder will be, in part, to continue research for development of more efficient breeding systems, development of genetically diverse populations for distribution to private companies, and identification of genetic systems for pest control.

In any event, the farmer, through his choice among hybrids and varieties offered for sale, determines what hybrids and varieties actually will be grown. Poor products fall from favor, and superior ones become widely accepted.

The Role of Land Grant Universities

The role and responsibilities of the land grant universities to the public are diffuse and complex. They span diverse activities from basic biological research in plant and animal genetics to advising farmers on specific matters such as which insecticide to apply to a particular field at a given time. Traditionally, the agricultural colleges and institutes in the land grant complex have devoted major attention to research and extension activities intended for the direct benefit of farmers and farm-related businesses. As these institutions evolve and respond to changing conditions and public criticism, the interest of consumers and the society at large are becoming more important in their activities.

Generally speaking, land grant colleges in the Corn Belt emphasize five major roles in direct relation to pest control activities.

1. Basic research on biology of pests and hosts. Both chemical and nonchemical segments of pest control are included in this category.
2. Breeding for disease and insect resistance and evaluating the resistance of existing varieties and hybrids.
3. Comparisons and evaluations of new and old pesticides supplied mainly by private industry. In some cases, economic analyses are performed along with the scientific studies.
4. The development of alternative strategies for pest control based on local farming systems, local and national regulations, economic factors, and the important regional pest problems and environmental conditions.
5. The planning and implementation of education and training programs mainly through the Extension Service. These vary depending upon the state and the personnel involved. Programs typically are directed toward farmers, distributors, and sometimes toward manufacturers of pest control products. The major goals are to make available the recommendations of pest control specialists and to disseminate general educational material in this area.

Much more detail could be presented here dealing with the pest control activities centered in and around the land grant universities. However, it is assumed that the main outlines of this work are known to the reader. Some additional discussion of the role of the land grant universities appears in later sections.

The Role of Other Universities

Much fundamental research in biology is conducted by scientists in public and private universities *outside* the land grant institutes and colleges of agriculture. The application of much of this research to pest control problems has not been immediately apparent. In particular, there seems to be little motivation in nonagricultural universities and departments to produce results of practical value or to make these results easily available to agricultural researchers. This problem is enhanced because of the way in which public research funding is allocated. Important barriers exist to the funding of agriculturally related research at non-land grant institutions.

The organisms and habitats chosen for study by scientists in these other institutions are often quite different from those of agricultural significance. There seems to be a bias against research environments created by or disturbed by human activity. This bias typically leads biologists to remote corners of the world rather than to agricultural environments. The result is that the conclusions and findings of such work are usually not directly applicable to agriculture but require adaptation and collaboration, which does not often occur in the usual course of events. This is apparent in bibliographies of research reports coming from the two sources, which typically have little overlap.

The barriers between these two scientific communities are strengthened by their different attitudes toward agriculture. Those who work in agriculture are usually more applied in their scientific outlook and are typically graduates of land grant universities. Those outside agriculture, but in related fields, are more theoretically oriented and tend to be uninterested in agricultural issues. Thus, until recently, both communities were inbred and, to some extent, provincial in outlook. More recently, changes in the academic and scientific job market have encouraged graduates from nonagricultural fields to seek employment in agricultural work. This may bridge some of the traditional barriers between the two.

The Role of Government Agencies

Government agencies engage in a number of pest control activities. These activities generally involve research on pest control methods, extension of these methods to farmers, and quarantine and pest control operations. At the federal level, the U.S. Department of Agriculture (USDA) is primarily responsible for these activities.

In addition to its support of the land grant university/state agricultural experiment station system through the Cooperative State Research Service, the USDA administers its own research system through the Agricultural Research Service. The USDA subdivides this research into the following six target goals:

1. to gain knowledge of the taxonomy, biology, ecology, physiology, pathology, metabolism, nutrition of pests, and host plants and animals;
2. to improve and develop means of controlling pests by nonpesticidal methods;
3. to develop safer and more effective pesticide-use patterns, formulations, and methods of application and improved methods for detecting, measuring, and eliminating or minimizing pesticide residues in plants, animals, their products, and in other parts of the environment;

4. to study the toxicity, pathology, and metabolism of pesticides and investigate levels, effect, and fate of their residues in plants, animals, their products, and in other parts of the environment;
5. to study economic aspects of pest control and its impact on the environment, determine the supply, requirements, and use of pesticides, and give assistance to control agencies and industries in emergencies; and
6. to control pests and protect the environment during and after control operations.

The extension services in each state are responsible for transferring new agricultural technologies from research and development centers (universities and experiment stations) to farmers. The costs of these extension activities are shared by the USDA, state land grant universities, and counties. Extension activities encompass a wide range of program areas, but concentrate on providing advice to farmers on agricultural production practices. Typically, extension programs on pest control problems have been directed towards supplying farmers with the knowledge necessary to identify pests and take specific control measures. However, in recent years, the U.S. Extension Service and the Animal and Plant Health Inspection Service (APHIS) have funded pilot programs for pest management. The objective of these programs has been to provide cooperating growers with specific analysis of their pest situation and the alternatives for pest control that are effective, economical, and environmentally sound. That is, the programs promote effective use of combinations of cultural, biological and chemical methods. Pilot programs are conducted in cooperation with farmers, grower organizations, industry, and state and federal agencies. In 1973, pilot programs in six midwestern states were started on insect and weed pests of corn. While earlier objectives were directed primarily toward regulation of insect densities, present pest management programs are an attempt to manage complex communities of both insects and weeds.

APHIS carries out inspection quarantine and regulatory activities through plant and animal disease and pest control programs in cooperation with state and local agencies and foreign governments. The inspection and quarantine functions are directed toward minimizing the entry into this country of foreign harmful insects, diseases, nematodes, and other pests of plants and animals. Once a crop pest has become established, APHIS works in cooperation with states to eradicate it or prevent its spread.

One of these measures may be a domestic quarantine to control the movement of any article that might spread the pest. APHIS also undertakes direct control operations such as spraying, fumigation, and release of sterile male insects. In recent years, APHIS programs and control operations have been directed toward a number of corn and soybean pests. Some of these pests are the Japanese beetle (*Popillia japonica* Newn), Khapra beetle (*Trogoderma granarium* Everts), soybean cyst nematode (*Heterodera glycines* Ichinohe), white fringed beetle (*Graphognathus* sp.), and European corn borer (*Ostrinia nubilalis* Hubner).

Manpower Allocated to Public Research on Pest Control

The bulk of public pest control research is done at the agricultural experiment stations in the land grant university complex of each state. Research at these state experiment stations is supported by a combination of state and federal funds. Federal funds are channeled through the Cooperative State Research Service of USDA. In addition, the USDA administers its own research system through the Agricultural Research Service. The level of this public research effort in 1972 on corn and soybeans is shown in Table 3-15. These figures are only an approximation since they do not include economic research on pest control problems.

Two Examples of Interinstitutional Cooperation

In many instances, successful pest control comes about as the result of cooperative work between private industry and the public sector. Two examples involving corn leaf blight are presented to illustrate. Both examples are drawn from Illinois experience, although important work on corn leaf blight is conducted at several midwestern agricultural experiment stations.

The first involves northern leaf blight of corn caused by the fungus *Helminthosporium turcicum*. This disease became important in the Corn Belt during the 1940s. Superior-yielding hybrids were susceptible, and known sources of resistance were late in maturity. The inherited resistance was complex and difficult to use in a plant breeding program. In 1961, a new source of resistance to this pathogen was discovered at the Illinois Agricultural Experiment Station. The resistance is due to a single dominant gene, which was designated *Ht*, and is highly

TABLE 3-15 Scientist Man-Years (SMY) and Funds Expended on Corn and Soybean Pest Control Research, Fiscal Year 1972

Item	Insect Control		Disease Control		Weed Control	
	SMY	Funds	SMY	Funds	SMY	Funds
Corn						
State Agricultural Experiment Stations	18.6	$1,068,185	27.3	$1,434,495	11.4	$686,741
USDA (Agricultural Research Service)	30.8	$1,220,784	15.8	$ 736,704	6.5	$188,423
TOTAL	49.4	$2,288,969	43.1	$2,171,199	17.9	$875,164
Soybeans						
State Agricultural Experiment Stations	12.0	$ 727,689	18.8	$ 880,103	10.0	$633,047
USDA (Agricultural Research Service)	4.9	$ 274,361	12.5	$ 753,359	7.0	$284,587
TOTAL	16.9	$ 921,050	31.3	$1,633,462	17.0	$917,634

SOURCE: Inventory of Agricultural Research FY 1972, Vol. I, Table 1, pp. 34-54.

effective. Sources of resistance were released to the public by the Illinois station. At the same time, a breeding program was initiated. This program eventually resulted in the release of 30 inbred lines converted to resistance. Supporting research at the State Experiment Station involved location of additional sources of resistance, genetic studies, chromosomal location of resistance genes, histological and physiological studies of resistance, pathogen variation, yield effects, and other studies. These results were published as research reports and presented to the seed industry and other corn workers at numerous local, state, national, and international meetings. Corn hybrids with the gene *Ht* are now widely grown in the sector. While it is not possible to put an accurate monetary value to the gene *Ht*, its value in preventing crop losses due to northern leaf blight infection has been estimated in excess of $200 million annually. The initial discovery as an outgrowth of research at a public agricultural experiment station was rapidly adapted by private industry to the general benefit of society.

The second example concerns the corn disease southern leaf blight, caused by *Helminthosporium maydis*. This disease developed in epidemic proportions in the sector in 1970 and destroyed 15-25 percent of the crop. Losses were low in 1971, and by 1972 the disease was again under control. The 1970 epidemic was caused by a new race of *H. maydis*, designated as race T. Race T was discovered and described through work done at the Illinois Agricultural Experiment Station. The susceptible reaction conditioned by the *cms*-T cytoplasm for male sterility, then used in the production of hybrid seed, was revealed. The work demonstrated that normal cytoplasm was resistant to the pathogen, and its usage was the most feasible means of controlling the disease.

Through conferences, meetings, and visitations, this information was acquired by the commercial seed industry, and by September 1970, most firms had elected to remove *cms*-T cytoplasm from usage. The experimental work also revealed that *cms*-C, *cms*-S, and other cytoplasms for male sterility reacted as normal cytoplasm to race T and conditioned resistance. These cytoplasms for male sterility had been collected through a previous U.S. Department of Agriculture and Illinois station research project. A collection of sterile cytoplasms and basic breeding stocks were released to the public by the Illinois station and the USDA in the fall of 1970. Further breeding work was advanced by private industry to the point where hybrid corn seed was produced commercially using some of these sterile cytoplasms in 1974. This represents another example where information and basic seed stocks generated at a state agricultural experiment station were rapidly utilized by private industry.

Pilot Pest Management Programs

As management of farm pests becomes more complex and sophisticated, the interaction between farmers and pest management experts becomes more important. The recognition of this need stimulated the Federal Agricultural Extension Service to establish in 1972 a six-state corn and soybean pilot pest management project. The major objective is to develop and apply insect control practices utilizing both chemical and nonchemical methods in a safe, effective, and economical way.

In meeting this objective, the central idea in the project is to establish a continuing flow of communication between the grower, the extension worker, and the research scientist. In each participating state, the Agricultural Extension Service coordinates the pilot project and selects a panel of participating farmers. Frequent and routine surveillance of growers' fields is made by scouts hired under the project. Their reports are reviewed critically by extension and research scientists, who then formulate control advisories to growers on an individual and regional basis.

At the moment, this program is in an embryonic stage and covers only a limited number of growers. Although it is still too early to assess the long-run potential for this approach, some tentative results have emerged. First, as might be expected, there is considerable enthusiasm among participating growers. Second, the application of chemical insecticides on corn has been reduced significantly. Third, the project apparently has prompted some private entrepreneurs to offer similar services on a fee basis.

The long-run economic and environmental success of these pilot projects will hinge upon their ability to prevent losses through prediction, surveillance, and early treatment where needed, as opposed to routine insurance-type treatments of chemicals or other control agents.

ADOPTION PATTERNS AMONG GROWERS

A pest management strategy may have numerous theoretical advantages and may appear strong in cost-benefit analyses. But until the necessary mechanisms for its implementation have been developed and the ideas involved in its use have been accepted by potential users, the approach is of little value. Thus the relative ease or difficulty of obtaining adoption is an important variable associated with pest management strategies.

At present, one of the characteristics of chemical pesticides is the rapidity with which they can be put into use. Adoption of new products or modifications of existing products can be relatively rapid. In general, the ability to use pesticides is not closely related to size of farming operation, and the idea of using chemical pesticides already has a major place in farming activities. In 1973, 98 percent of the Iowa and Illinois farmers interviewed in the von Rumker study said they used soybean herbicides; 99-100 percent used corn herbicides (von Rumker and Horay 1974). In the same year, 53 percent of Iowa corn growers and 70 percent of Illinois corn growers used corn insecticides. Unless there is something unique about a new chemical pesticide in its handling, application, or in the results to be expected, it is likely to be viewed by farmers, dealers, and applicators as similar to products already in wide use. In addition, systems for the promotion, distribution, and application of chemical pesticides already are highly developed.

In addition, public agencies are already in existence to evaluate possible health and environmental impacts of new chemicals and to provide such information to potential users. The major problem for the manufacturer of a new chemical pesticide, after needed federal approval has been obtained, is to convince potential dealers and growers that the new product is superior to other pesticides. In this situation, it is not necessary to sell dealers and farmers on the idea of using chemicals or to develop the distribution channels needed to make them available.

In general, farmers cannot directly answer all their own questions about alternative pest control strategies and their effects. They are dependent for information on reports of research by various public and private agencies, including universities and commercial firms. Many farmers also receive information from personal contacts with friends and acquaintances. In a study by Beal *et al.* (1966), Iowa farmers were presented with a list of types of sources of information on agricultural chemicals and were asked which of the sources they were presently using. The following were among the responses:

Source of Information	Percent Using
Farm magazines and farm papers	94
Farm Journal	70
Wallaces Farmer	66
Successful Farming	57
Container in which product comes	90
Other farmers in the community	68
Local agricultural chemical dealers	61
Radio	49
County extension personnel	48
Television	42
Agricultural chemical company publications	42
Agricultural Extension publications	35
Family members	25

Environmental publications were not among the listed publications. That use of such sources was probably small, however, is indicated by the fact that only four farmers mentioned "other publications."

R. von Rumker collected data on use of information sources by Iowa and Illinois farmers in 1973. Those findings included the following:

Source of Information	Percent Using	
	Iowa	Illinois
Pesticide sellers	95	75
Neighbors, friends	84	50
Pesticide label	81	50
Farm magazines	81	59
Trade meetings	41	29
Other publications	38	13
University meetings	36	26
Radio	34	10
County agents	29	34
Extension specialists	26	29
Television	26	8
Pesticide manufacturers representatives	22	31

While there are differences between the results found by Beal and von Rumker, one important similarity is that in both studies the following were among the top four sources in percent of farmers using: pesticide sellers (local agricultural chemicals dealers), neighbors and friends (other farmers in the community), pesticide label (container in which product comes), and farm magazines.

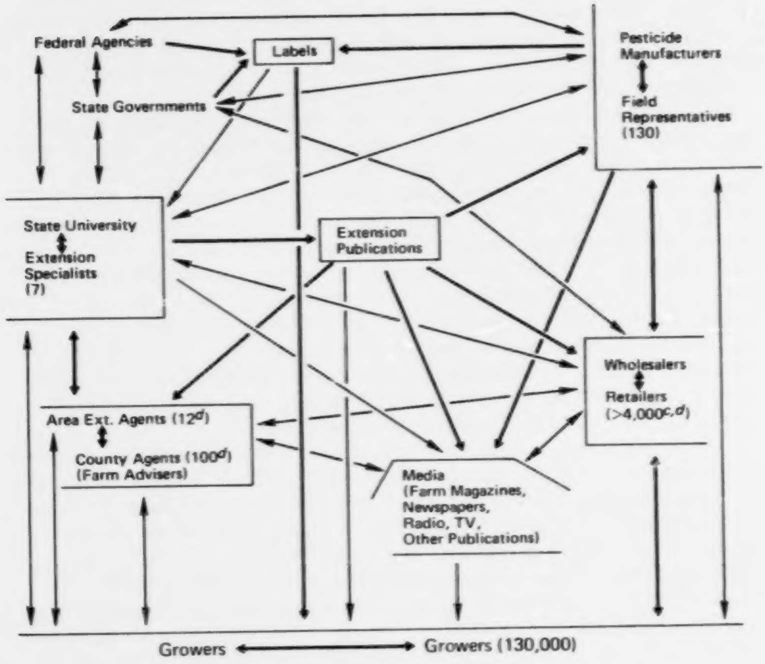
The Iowa and Illinois farmers were also asked to rate the usefulness of information sources. The sources rated by the farmers as most useful were pesticide labels; pesticide sellers; neighbors, friends, and relatives; and university extension specialists. The lowest score for usefulness was received by television.

In assessing the importance of various information sources, it is important to realize that for most farmers the diffusion of information on pesticides is a multistage process. The number of farmers reached directly by sources such as extension publications, for example, is only a partial indicator of the total number who eventually (and indirectly) gain access to the information contained in such publications. Chemical company representatives, extension personnel, the media, and other farmers often serve as intermediaries in the transfer of information. The complexity of the interactions between various information sources is suggested by Figure 3-1, reproduced from the von Rumker study.

In assessing the ease with which various kinds of messages about pesticide use can be diffused to a target population, it is well to remember that according to the von Rumker study, representatives of the pesticide manufacturing companies outnumbered ". . . extension specialists by a margin of almost 20 to 1. . . ." Nevertheless, von Rumker also points out that the major difference between Iowa and Illinois in the percent of soybean acres treated for green cloverworm in 1973 was attributed to different techniques used by the two extension services in determining economic injury levels. Thus it seems that extension recommendations may be underrated by farmers as a basic source of information. This example demonstrates the complexity of information flows as illustrated in Figure 3-1.

While the distribution and adoption of pest control strategies based on chemicals and related products in the Corn Belt is relatively easy and rapid, the adoption of other forms of pest control in corn and soybeans is less certain. If a new approach is to be adopted, it will have to be accepted by farmers. Some approaches will also require acceptance by others, such as product manufacturers and distributors. Factors affecting farmers' decisions will be emphasized here. Chief among these factors is profitability.

It has not been demonstrated that farmers are always profit maximizers, and the impact of a new pest management


Federal Agencies
Labels
Pesticide Manufacturers
Field Representatives (130)
State Governments
State University
Extension Specialists (7)
Extension Publications
Wholesalers
Retailers (>4,000[c,d])
Area Ext. Agents (12[d])
County Agents (100[d]) (Farm Advisers)
Media (Farm Magazines, Newspapers, Radio, TV, Other Publications)
Growers
Growers (130,000)

[a] Heavy lines indicate predominant routes.

[b] Numbers in parentheses indicate approximate number of workers in specified category in the State of Iowa.

[c] Assumptions: There are about 1,250 sellers of agricultural pesticides in Iowa, and an average of 3 persons per outlet selling pesticides, plus about 550 commercial applicators retailing agricultural pesticides.

[d] Deal with pesticide problems only part-time.

FIGURE 3-1 Sources and Routes of Information on the Use of Agricultural Pesticides in the Midwest.[a,b]

strategy or product on profits will not be the only factor considered. Yet, profitability is likely to be one of the most important issues. Any new approach usually will be evaluated in comparison with other alternatives. If any of the alternatives involve costs that are borne by society (e.g., environmental problems) or by hired workers (e.g., health hazards) rather than by the farmer decision makers, these costs will generally receive relatively little weight in farmers' decisions. It is not realistic to expect individual farmers to voluntarily forego income by selecting strategies that are less damaging ecologically. Some may be willing to do so; most will not, even though farmers as a group are sensitive to social and environmental issues. This question is at the heart of "externality" problems discussed earlier.

Less-profitable alternatives, such as "integrated pest management systems," or biological methods of control may involve lower environmental costs. If they are to be selected over scheduled applications of chemical pesticides, for example, it will be necessary either to reward farmers for using integrated pest management or to charge the sector in some way for the adverse environmental impact, if any, of chemical pesticide applications. Proposed programs of this type attempt to internalize the externalities to the producing sector involved. Providing farmers with information on long-run buildup of residues, increased resistance of pest strains, and so on, may be helpful but will not solve the problems.

Risk is also a factor conditioning the adoption of pest control strategies in the Corn Belt. From the perspective of many farmers, pest control is not to be viewed as simply a technique for increasing profit, but rather as a way of assuring that crop failures do not occur. Corn Belt farmers are now reasonably familiar with the effects of chemical insect and weed control upon the riskiness of their cropping operations. Major changes in pest management techniques will introduce unknown elements into the risk situation. Even if budgeting and profitability studies based on average data are favorable for a new approach, its effect on yield and production variability over the long run probably will be uncertain. This will add difficulty and slow down potential adoption.

Information from the von Rumker study suggests, however, that farmers are willing to take advice on pesticide applications. About 85 percent of the Iowa growers and 63 percent of Illinois growers interviewed said that if an advisory service recommended that some or all of their fields should not be treated because of low pest infestations, they would follow the advice. Additionally "about one-half of all respondents stated that they would be willing to pay a fee for such a service, ranging from 5 cents to $5 per acre, averaging 76 cents per acre in Iowa, 70 cents per acre in Illinois" (von Rumker and Horay 1974).

Complexity is a factor affecting potential farm adoption. Most commercial farms in the Corn Belt are complex, highly capitalized businesses. The farm operators who produce the bulk of the output of corn and soybeans are, for the most part, rather sophisticated managers. They are used to dealing with complex production activities. This is especially true in comparison with earlier generations of farmers. It is not clear, therefore, how much impact the complexity of a new pest management strategy will have on its adoption. It is probably true that, other things being equal, the less complicated a new pest management strategy is, the more likely it is to be adopted (and the more quickly). Added complexity of the control strategy is probably a deterrent to adoption when it involves more sophisticated management and decision making rather than more elaborate mechanical or chemical products.

It is also likely that a new pest management strategy that requires no major alterations in current production practices will be adopted before one requiring major alterations, especially if these changes also require expenditures for new machinery or inputs. Changed cultural practices such as strip cropping or new crop rotations are examples of possible strategies (or components of strategies) that would involve significant changes in farmers' activities.

Some pest management strategies may require the development of new organizational forms and expertise before they can be implemented. In these cases, it is not simply a matter of getting adoption by farmers but also of developing a support system and, perhaps, obtaining legal sanctions. Integrated pest management systems that employ licensed pest management specialists are examples of this. Not only do the organizational systems in which the specialists would be employed and the ties between these systems and the farmers need to be developed, but the specialists themselves have to be trained. The need to develop supporting structures is then an important factor that can influence the adoption of alternative pest management strategies. The six-state pilot pest management program discussed earlier is an example of this kind of development.

The Interrelationships Among Institutions

The linkages between and among public and private institutions in the agricultural development of the United States are complex and long standing. Of primary interest here are the lines of influence and interactions involved in the discovery, development, and delivery of technological change to the farm sector and, hence, to society at large. The traditional pattern of relationships might be summarized as follows.

The land grant universities and government agencies in agriculture pursue, among other things, both basic and applied research to uncover improved production methods for use by farmers. These include new or better seeds, machines, fertilizers, and pest control methods. Through their extension functions, the land grant universities are charged with the educational responsibility to bring the latest and best of these results to the producers.

Many, if not most, of these technical achievements ultimately are embodied in products and commodities that are produced off-farm by industry and sold to farmers as productive inputs. Thus, private industry, broadly viewed, has a considerable stake in the pace and direction of technological research and the change occurring in agriculture. The chemical and biological technologies and products that emerged so strongly in the 1950s and 1960s illustrate clearly the tight relationship between applied agricultural research and agribusiness generally. The substantial resources now devoted to developmental research by large fertilizer, seed, and chemical firms continue to reflect this relationship.

Most technological change increases output and reduces cost (in a discounted average cost or marginal cost context). In a largely competitive economy, these cost reductions are soon passed along to consumers in lower relative prices. Even though some technological gains have been captured in rising land values in the United States and in imperfectly competitive market subsectors, there is general agreement that much of the long-run benefit of agricultural research has been diffused widely through the economy.

In a broad sense, these conditions traditionally contributed to an easy and productive relationship among land grant universities, farmers, agribusiness firms, numerous government agencies, and the general public. Everyone's interest usually appeared to be running in the same direction. In the 1950s, and more so in the 1960s, some strains began to appear in the seams of this fabric. An early evidence of conflict was the uneasy feeling among some social scientists and others that rapid technical advance in agriculture, financed by public funds, was somehow inconsistent with the piling up of surplus stocks and with land diversion in connection with farm price and income support. Similarly, the massive postwar reduction in farm numbers and rural residents in the presence of rapid technical advance appeared, to some observers, to be a questionable benefit, especially in view of the mounting and seemingly insoluble urban problems of the 1960s and 1970s. More recently, externalities closely associated with chemical pest control methods have added further strain to the traditional nexus between public and private agricultural interests.

A number of people and organizations both inside and outside the agricultural sector are openly critical of the whole system. Much of the criticism swirls around the lack of explicit attention to these social and environmental externalities by the public agencies, mainly the land grant colleges. Some are broad questions of social objectives and goals. Others are more narrowly defined issues focused on specific problems. A recent publication of the Agribusiness Accountability Project crystallizes these critical views of the land grant complex (Hightower 1973). The authors of this report and their supporters feel that both the research and extension functions of the land grant complex have failed to serve adequately the broad interests of rural America and the nation at large.

There seems to be little need to elaborate the multitude of positive and socially productive interrelationships among these institutions and the people in them insofar as pest control is concerned. These are generally well known and are dominant in the sector. In the paragraphs that follow, some brief comments on the general nature and direction of these criticisms are presented as they relate to pest control.

Organization and Coordination in Public Research

The mission of public agricultural research institutions includes both long-range investigation and short-term adaptation of existing knowledge to slightly new situations. But in practice, it has been more successful in the second mission than in the first. There are various reasons for this:

1. Support for research, especially at a state level but also at the federal level, depends on the demonstration that the research pays off. This usually means working toward immediate results since the consumers of agricultural science generally have a philosophy that takes pride in pragmatism and problem solution. This philosophy is shared by many agricultural researchers themselves, who, therefore, do not feel coerced.

2. The relations between the public and private sectors of research often tend to be more cooperative than in conflict. Corporations give grants for research in the areas of interest to them; university departments often carry out field tests of products that become commercially important. Personnel move freely between the private and public sector. Universities train students who take jobs in industry. For these reasons, there is a general community of outlook and a common scientific culture between private and public research.

3. The service orientation of some public research means that activities are concentrated on providing techniques or materials adapted to current practices and crops and to present problems. The administrative organization of research into separate departments of entomology, plant pathology, plant breeding, agronomy, and others means that work on a particular pest problem may be spread over several departments. Overall coordination of control strategy is more difficult as is the anticipation of new problems. There is the risk that present practice may define the boundaries of the problem. For example, plant breeding work proceeds on an assumption of monoculture rather than the selection of varieties for mixed planting. This is because pure stands are the norm and the existing machinery is designed for a pure stand. Thus, independently directed short-term research has the effect of reinforcing the present trajectory of technological development.

4. For reasons mentioned earlier, administrative and philosophical differences can and often do make cooperation between agricultural colleges or stations and urban universities more difficult. For example, although the cultivated field is a complex ecosystem, the community ecology of a cornfield is still unknown and there is no good survey of the arthropod fauna, soil animals, or microflora much less an analysis of total community structure.

5. The effective unit of pest control depends on the mobility of the pest. For some groups, a whole region rather than a single farm is the appropriate unit. It is only recently that some preliminary work in regional control strategy has gotten under way.

Private Research and Product Development

The research and development divisions of companies engaged in the production of pesticides are charged with the development of marketable commodities. The 3-4 percent of a corporate budget going into R&D must compete with alternative investments on the basis of profitability. Within the research divisions, projects compete and workers are judged at least partly on their contribution to income. Up to now, pest control research has been marketed most readily as chemical compounds, mixtures of compounds, and application apparatus. Since most pesticides are produced by petroleum and chemical companies, the private research emphasis in this direction is reinforced.

Within the field of chemical research, the main thrust is toward large-scale screening within classes of compounds that have proved effective in the past. This makes it most likely that nonspecific substances will be found, and these are most marketable. It is also unlikely that synergistic effects will be studied, since the number of pairs of compounds to be screened is about half the square of the number of compounds. Thus, a screening of 100 compounds would require the study of 4,950 pairs.

This approach to research has other consequences. The intellectual detours needed to obtain a fundamental understanding of the pharmacology, physiology, and ecology of pest control are generally discounted in favor of immediate results from trial-and-error screening. This tendency is sometimes counteracted by the willingness of some firms to allow researchers the freedom to devote a fraction of their time to individual projects as a fringe benefit.

For the most part, large private firms would prefer to have the fundamental research done by universities and product development left to themselves. In addition, smaller firms, without research and development capacity, presumably want public institutions to do much of the applied product development work in the pest control field. In either case, the private industry has substantial interest in the direction and scope of research by public institutions. It is at this juncture that possible conflicts of interest between private industry and public agencies can occur. The traditional close relationship between the two provides a focal point for critical observation of the system.

A second consequence of corporate research strategy is that the investigation of possible dangers of pesticides may not be comprehensive enough. Usually some acute toxicity studies are carried out on a few organisms. Though some do it, no company could be expected to invest much creative energy in exploring the harmfulness of its products beyond that required by law. Rather, its researchers are most often advocates of their products.

Employment contracts of chemists who work for private chemical companies may prohibit the individual scientist from taking any public action that can be construed as harmful to the firm.

The Extension Service and Its Role

Extension services in the land grant system are in an especially sensitive, difficult, and demanding position in the pest control picture. County agents and area specialists are not salesmen for products or services, yet they must know the relative characteristics and performance of commercial products. They are not usually farmers themselves, yet their traditional role has long emphasized service to farmers in their production activities. They are not usually well trained in ecology or environmental protection, yet they are often asked about the ecological aspects of various products and techniques. Those extension agents closely involved in pest control or related problems are not often sociologists or rural social scientists, yet they may be accused of helping only large, efficient producers rather than small, inefficient, part-time farmers struggling along with low incomes.

This fragmentation and confusion of roles and obligations in recent times has made the extension service a lightning rod for much of the criticism leveled at the total land grant system. These general problems carry over to a substantial degree into the pest control field. However, it may be true that the role of the extension service is less complex in the corn/soybean sector than in other sectors with a greater crop or pest diversity. First, pest management in the sector involves major efforts in weed control. Externality difficulties with herbicides seem to be less than with insecticides. Second, in the corn/soybean sector, the drive toward larger and larger farms in pursuit of technical efficiency has not progressed quite as fast or quite as far as in other sectors where (1) family-sized operations are becoming scarcer and (2) the size-distribution between the larger and the smaller units is becoming heavily skewed toward huge operations.

Still, the role of the land grant extension service in the corn/soybean pest control field remains difficult and sensitive. Working out a balance of goals, expertise, and public responsibility is a prime issue in the evolution of the land grant extension function. The challenge is to strengthen the broader, environmental, and educational aspects of extension work without losing the technical and farm-oriented management expertise that generally exists.

Countercultural and Extrainstitutional Activities

Standing outside of the traditional system of agricultural research extension and farming are a number of groups, some interested in alternative technologies for agriculture and some in alternative lifestyles generally. Their origins and ideas are diverse. They include organic gardeners, health food enthusiasts, popular ecology groups, communal farming and living groups, and others. Most share a critical opposition to chemical pest control and other aspects of contemporary agricultural technology. To some extent, their views emerge in publications such as *Organic Gardening and Farming, The New Alchemists, Mother Earth News,* and a number of others.

At present, there is little contact between these groups, their ideas, and the public research establishment. The experimental facilities of this group of critics are minimal. Their ideas and results are presented with inadequate data that are often poorly controlled and heavily anecdotal. Their innovations are usually appropriate only for small-scale farming and must be adapted before large-scale use would be possible. Their ideas are not easily transformed into marketable commodities, and many would require significant social and legal changes in this country. Yet, their criticism is too often dismissed as the work of cranks. It may well be that some of the insights and ideas emerging from these groups merit serious consideration in future research activities.

4

THE FUTURE OF PEST CONTROL IN CORN AND SOYBEANS

IMPLICATIONS OF CURRENT TRENDS

One way to assess the future pest control scene is to examine both the current and historical situation and then project into the future the trends and patterns they represent. The typical method for doing projections of this kind is to make a series of assumptions about the future economic, political, and scientific environment based on present knowledge. Then the implications of these assumptions are examined for the sector or the phenomena in question.

At the moment, the U.S. agricultural sector seems to be in a stage of rapid transition from a surplus capacity, low-price sector to a storage-dominated, high-price sector. Yet, no one knows for sure if the price and income boom of 1972-1973 will continue and grow, or dissipate into the familiar situation of the 1960s. Consequently, specifying broad assumptions about the future direction of Corn Belt agriculture is risky. In addition, the nature of scientific discovery and development does not lend itself to smooth projection. Nevertheless, a series of basic assumptions was made to evaluate the direction that current trends in pest control methods seem to be taking us.

Basic Assumptions

These assumptions postulate no massive or sudden changes in the economic, environmental, political, or scientific setting. They are to be viewed as middle-of-the-road assumptions about future trends.

1. The domestic and foreign commercial demand for U.S. corn and soybeans will continue to be strong. In both products, exports likely will grow in importance relative to total disappearance.
2. Prices for corn and soybeans will remain strong relative to other crop and livestock enterprises in the Corn Belt. The ratio of soybean to corn prices will remain approximately 2.5/1.0, although the actual level of prices may move up and down substantially over short periods.
3. General price inflation will continue in all sectors of the economy at about 5-10 percent per year.
4. No real shortage of energy for farm production will emerge, but prices for fuels and related inputs will increase faster than the general level of other inputs' prices. The same situation will probably be true in fertilizer. Chemical pesticide prices will increase somewhat faster than inputs other than fuel and fertilizer.
5. The federal government will not establish a sizeable inventory of reserve grain stocks for stabilization purposes, although some modest efforts along this line may emerge. Similarly, government commitments for international food aid will remain small relative to the commercial market, especially in feed grains and oilseeds.
6. Government farm policy will not return to acreage diversion as a keystone of production policy. Some voluntary corn acreage diversion programs may emerge from time to time in the future, but they will not be applied to soybeans.
7. Strengthening of existing regulations or enactment of new laws concerning pollution or environmental quality will not substantially affect the corn/soybean sector. However, the regulations for implementing FEPCA are now being developed. They relate mainly to pesticide application and use and may add new constraints and costs to chemical treatment of corn/soybean pests.

These points are assumptions for purposes of discussion. They are not predictions or conclusions about the future state of affairs. These assumptions reflect current trends and the present situation. The picture could change drastically overnight, and some of these assumptions might no longer even be plausible.

Trends in Cultural Practices

Some assessment of future trends in cultural practices for corn and soybeans can be made by examining the current practices of innovative farmers. Techniques that the innovators find successful generally are adapted over time by the majority of farmers.

Farm equipment size, although technically not a cultural practice, has major effects on farm size and timeliness of operations. It appears that equipment size will continue to increase. Corn and soybean planters of eight rows or more now are being adopted by larger Corn Belt operators and will become more common in the future. Tractor horsepower will increase as four-wheel drive tractors become more common. Harvesting equipment will grow in size and operating speed.

Reduced tillage will be used on more acres. This reduction in tillage will range from planting in the crop residue with no seedbed preparation to decreases in the frequency of plowing and of secondary tillage, particularly following soybeans.

Narrow-row production of soybeans will increase. Corn has not shown consistent increases in yield when row widths below 75 cm (30 in.) are used. So there is little grower interest in reduced row spacing for that crop. Although soybeans have shown consistently higher yields in narrow rows (less than 50 cm), Corn Belt farmers have been reluctant to reduce row spacing, since the same equipment is used for both soybeans and corn. Separate narrow equipment for soybeans has not been profitable. The need for some mechanical cultivation also has slowed the shift to narrow rows. The recent increase in profit margins for soybeans and improved postemergence herbicides may hasten the shift to narrower rows.

Earlier planting dates are being used by innovators for both corn and soybeans. Recent research has identified optimum planting dates for most geographic areas, and farmers are attempting to plant both crops as near as possible to the optimum. These optimum dates are generally 10 days or more earlier than those previously used by farmers.

No shift to hybrids or varieties that mature earlier is likely unless energy supplies for drying become limited, which is not expected. Full-season varieties still give maximum yields for most areas.

Plant populations have begun to level off in corn. Plants per acre will increase slightly in soybeans with some narrow-row production.

Fertilizer usage for corn and soybeans will not increase markedly over present per acre rates. High rates of phosphorous and potassium application over the past two decades have increased the level of each in the soil. Since no yield increases occur with further phosphorus and potassium application rates on such soils, slight reductions in fertilizer use may occur. High nitrogen applications are now common on corn, and it is unlikely that these rates will increase very much.

Hybrids and varieties with higher yield potential will be developed by plant breeders. No major breakthroughs in yield are envisioned, but steady increase in hybrid and variety performance will occur.

Double cropping of corn or soybeans after small grains is expanding in the southern part of the corn/soybean sector and may continue to spread. Moisture conservation is important for success of the second crop. Therefore, no tillage or reduced tillage systems often will be used.

Implications for Weed Control

The trends toward reduced tillage and double cropping will intensify the use of effective herbicides. In fact, the keystone of reduced and minimum tillage technology is good, nonmechanical weed control. Nearly all current and prospective methods of weed control in corn and soybeans involve continued usage of herbicides. A strong research thrust toward developing herbicide treatments that are more effective and more reliable is evident and will continue if present trends persist. At present, there are approximately 10 compounds with promise being evaluated for weed control in corn and 6 in soybeans. Of particular interest is a nonpersistent, foliarly applied quack grass herbicide that could substantially reduce the losses from this weed, the most serious perennial, grassy weed in corn and soybeans. The herbicides that will control emerged broadleaf and grassy weeds seem certain to increase soybean yields as they come into use.

Greater effectiveness and reliability of weed control in corn and soybeans increase the possibility of a substantial reduction in fuel requirements for corn and soybean production through the elimination of much of the tillage used in conventional corn and soybean production.

Implications for Insect Control

Minimum tillage practices increase the diversity of pest problems, elevate some insects to pest status, and require modification of generally accepted treatment practices. In general, all insects that are a problem in conventional tillage are also a problem with minimum tillage. The major insect problems that appear to be increased in minimum tillage include armyworm and corn stalk borers. The generally heavy plant growth with reduced tillage makes it difficult to obtain insect control with currently common methods. Effective chemical control may require an additional trip over the field with application equipment. New pest problems that have come to the fore in reduced-tillage systems include slugs and rodents.

The increase in commodity demand and prices has increased the total area planted to corn and soybeans. As a result of the greater potential return, the economic threshold, however calculated, is reduced; and producers become more conscious of potential losses due to pests. Thus the tendency of many farmers to attempt prophylactic or insurance-type insect treatments probably will increase even in the face of current programs designed to add selectivity to insect control methods.

Some increase in corn and soybean acreage has been accomplished by double cropping and by cultivation of less-productive lands. The latter frequently involves modified tillage systems that also may intensify insect problems. Double cropping (usually soybeans following wheat) also will increase. This practice changes the normal synchrony of pest development and soybean plant development. It is projected that double cropping will increase the need for insect control. This is because the insect population, which is in a more advanced stage late in the season, will be able to attack the small, second-crop plants.

The crucial point is that any modification of a cultural or production practice generally has broader effects than the primary objective. Effects of cultural or production practices may be positive in one aspect and negative in another. The obvious point is that modification of a practice has multiple and often unexpected effects. In general, the current trends in the economics and cultural practices of corn and soybeans will intensify both the desire and the need to control insect pests. The result may be some tendency toward more chemical insecticide applications on corn and soybeans even in the face of public efforts to promote more sophistication and selection in the pest control field.

Implications for Plant Disease Control

Double cropping and minimum tillage will have implications for plant disease control. Double cropping will have a greater impact on corn than on soybeans, especially if the alternate crop is wheat or barley. The causal agents of some diseases are common to all three grass crops and will tend to increase in prevalence. A delay in the planting of corn also will expose the crop when it is in a juvenile and more susceptible condition to spores of disease-producing organisms reproducing on the earlier-planted fields. Disease losses are also greater when young plants are infected than when plants are first infected near maturity. The latter is also true for soybeans.

Unless crops are rotated, both corn and soybeans will suffer greater disease hazards with minimum tillage. The causal agents of many diseases overwinter in undecomposed, infected crop refuse from the previous season. These organisms are mostly destroyed when crop refuse is covered with soil. Other control methods, such as increased disease resistance, might offset this loss of crop sanitation in some cases.

Implications for the Environment

The implications of current trends for the environment hinges mostly on the amounts and types of pest control chemicals used. Current production trends, together with likely economic developments, suggest continued increase in the use of herbicides in weed control. With reduced tillage systems, expanding acreage, and more intensive production of corn and soybeans, additional problems of spillover/drift are likely to occur. Up to now, there is no evidence of long-run buildup or environmental persistence of herbicides in the corn/soybean sector. In addition, Environmental Protection Agency standards limit the clearance of highly persistent herbicides.

The environmental implications of insecticide use appear to be mixed. On one hand, the production and price trends suggest increased use of insecticides in the sector mainly as a result of expanding acreage, reduced tillage, and falling economic thresholds of treatment. On the other hand, the decreased use of the most persistent chemicals, increasing selectivity and sophistication in the application of insecticides, and the likelihood that experienced applicators will do more of the actual treatment all suggest a lessening in the undesirable environmental effects from insecticides in corn and soybeans. The net effect on the environment is not clear, but problems may well occur.

The overall picture is one of increased chemical load on the corn/soybean sector. The relative growth of herbicides and the trend to less-persistent and more carefully applied insecticides offset to some extent the potential environmental impact of this increased load.

Implications for Rural People and Institutions

Earlier it was argued that among the indirect or nonmarket effects of current and past pest control practices was the part they played in the evolution of a complex, efficient, and highly capitalized system of agricultural production. A notable characteristic of this system has been the continual substitution of capital for labor. Corn and soybean pest control technologies alone have not caused this phenomenon. However, they have been an integral part of it.

The long-run pressures of these technological and social changes have had important effects on rural communities, urban centers, individuals and families who have left farming and rural areas, farm workers, and the American public at large. In addition, the changes that pesticide technologies have helped to bring about have had important psychological implications for those who remain on farms.

The continuation of past trends in agricultural technology, including pest control practices in the Corn Belt, will continue to promote the movement of people from rural places to urban and suburban centers, with resulting problems for both. The migration from rural areas to large population centers will continue, though at a slower rate than previously. To the extent that this migration is a social problem for both rural and urban areas, it is a factor that should be considered in assessing alternative approaches to pest management.

Since the number of persons now living on farms is much smaller than in the past and since many of them derive part of their income from nonfarm sources, the absolute number of families leaving agriculture in the 1970s will not be as great as it has been in the last three decades. The continuation of current trends in pest control practices, along with other changes in agriculture, will result in some families having to leave (or not being able to move to) farms and rural areas. As in the past, it is to be expected that for some the adjustment will be smooth; for others it will be filled with problems and disappointments.

However, other factors may intervene to influence future population location and employment opportunities. Whether the U.S. population continues to become increasingly concentrated in metropolitan areas could be greatly influenced, for example, by the development of national policies directed at encouraging location and development of job opportunities outside major urban centers. Such policy changes could easily overshadow any effects due to continued trends in agricultural technology. Yet, the indirect effects on both rural and urban communities of continuing current pest control practices and regulations should receive more attention in the future than they have in the past.

One advantage for individual farmers of using up-to-date pest control practices is that in the short run it reduces the risk of major crop loss due to pests. Along with hail and wind insurance and government price support activities, it helps insure individual farm incomes. Given the highly capitalized nature of modern farming, this has potentially great psychic benefits for individual farmers and their families.

This is not to suggest, however, that the only psychological impact of pest control practices in the future will be to reduce worry of crop loss. Adverse psychological implications of current pest control practices, mentioned earlier, can be expected to be important to some farmers in the future and may even increase in importance. These include fear of not being able to compete effectively in agriculture, concern about environmental effects, and anxiety about personal safety in using pesticides. These psychological impacts may be lessened somewhat by the continuing trend toward nonpersistent insecticides and improved herbicides and by the more careful applications indicated under the new regulations of FEPCA. A continuing worldwide shortage of food, along with related production-increasing policies by the federal government, may work to strengthen farmers' conclusions that chemical pest control methods are required to overcome hunger and malnutrition. Continuation of current trends will provide mixed and conflicting pressures on rural people and institutions.

Backup Systems of Pest Control

Adequate production of corn and soybeans in the Midwest is important to the welfare of the United States and to some foreign countries. A breakdown in production due to an unexpected pest problem could have serious repercussions. An often-cited example is the concern generated by the 1970 corn blight epidemic.

The impact of a new pest outbreak would depend partly on the time required by agricultural scientists to develop appropriate control measures. The speed with which control measures could be developed and implemented would depend on the nature of the pest and the availability of "backup" control practices or materials.

A backup system is any pest control practice or material not presently needed to control losses from present pests. Backup systems include genetic resistance that could control new races of insects or diseases; new crops that could substitute for corn and soybeans; and chemicals for weed, insect, or disease control not presently required. An assessment of backup systems for control of future pest outbreaks is needed to be certain that a rapid response could be made to insure adequate food production.

If corn or soybeans were severely attacked by a new pest or a new strain of a present one, some acreage previously devoted to the two crops could be planted to new crops until adequate control measures were developed. The feasibility of acreage substitution would depend on the availability, productiveness, and market value of new crops. Availability would include sources of seed for planting and proper equipment and technology for production, handling, marketing, and processing. Information concerning productiveness and market value of a new crop would require agronomic and economic comparisons with corn, soybeans, and other alternatives.

Some acreage substitution could be made with crops presently grown in the corn-soybean sector. Wheat, barley, oats, and other small grains could be expanded, especially in periods of high grain prices. Flax could serve as a partial substitute oil source if soybean output were curtailed. Sorghum could substitute for corn in livestock feeding. Production of these crops could be readily handled with a minimal amount of equipment changes. Handling and processing generally could be accomplished with application of present technology and equipment available in the Midwest.

The substitution of corn or soybeans with sunflowers, field beans, safflower, triticales, or crops not currently grown in the corn-soybean belt would be difficult. The availability and productiveness of new crops not commercially grown in the corn-soybean belt are essentially unknown. Virtually no research on these crops is conducted by either the public or private sector. The lack of adequate research on new crops severely limits backup strategy. In addition, the small markets for these commodities might easily be swamped in the short run. Special backup programs to insure farmers at least some financial reward for switching to these crops probably would be required.

Chemicals can be used as a backup system for control of new pests. An effective chemical backup system would require an inventory of chemicals with potential for control, adequate facilities for synthesis of the chemical, and emergency procedures for providing legal permission to use restricted materials. A concerted effort should be made to establish a chemical backup system. Such an effort would require coordination of information from the chemical industry, public institutions, and regulatory agencies.

Thousands of new chemical compounds are evaluated each year by the private sector. The extent that each compound is evaluated depends on its ability to show promise in various tests. Many compounds are found that show promise for pest control but are never released because of inadequate market potential based on present needs. A fungicide for control of corn leaf blight presently would be uneconomical to produce because of adequate genetic resistance in commercial varieties. Such a compound could be vital, however, to corn production if new disease races develop that cannot be controlled by genetic means. Information on the potential use of unreleased compounds could be gathered from the private sector, the Defense Department, and public scientists.

The ability to synthesize backup chemicals should be assessed. Some existing facilities could be converted to production of new compounds if the need arises. Production of some other chemicals would require completely new equipment. Advance planning for chemical production in a variety of circumstances is required for an effective backup system.

If a new pest outbreak occurred, it probably would be necessary to consider the use of various compounds without adequate environmental impact studies. Procedures for emergency use of backup compounds over large agricultural areas are needed. Failure to develop guidelines for emergency registration could severely limit the effectiveness of a chemical backup system.

The use of genetic resistance for control of new pests can be part of an effective backup system. The corn leaf blight did much to focus attention on the genetic vulnerability of U.S. corn and soybeans. An ad hoc subcommittee of the Agricultural Research Policy Advisory Committee has recommended actions and policies for minimizing the genetic vulnerability of our major crops (USDA and National Association of State Universities and Land Grant Colleges 1973). Their report also can be considered as a description of procedures for developing an adequate genetic backup system. Some of the key parts of an effective genetic backup system include conservation and management of native corn and soybean varieties throughout the world, utilization of exotic varieties to develop genetically diverse hybrids and varieties, and monitoring of plant pests to detect problems before they expand to an epidemic.

The concept of backup systems for pest control is difficult to implement because of the uncertainty of future pest problems. Considerable research could be expended on new crops, chemical compounds, and genetic resistance without any guarantee of their future need. Nevertheless, maintaining reliable food production in the corn-soybean belt may someday require the utilization of one or more of these major backup strategies.

SOME FUTURE DIRECTIONS IN PEST CONTROL FOR CORN AND SOYBEANS

Any evaluation of present pest control technology and research should include a comparison of the actual and evolving practices with alternative possibilities. Otherwise the present is compared only with the past, the use of modern technology is compared only to its absence, and we may consider only secondary modifications of the ways things are done now. The actual situation always seems more sound and reliable than untried possibilities. In order for alternatives to be seriously considered, they have to be developed in some detail with some indication of conditions needed for their application.

The final stage in the determination of what technology is used is its adoption by farmers. This is determined by the economic rationality of farmers and farm managers. The widespread adoption of any new product or practice in U.S. agriculture, as in industry and trade, is decided ultimately on the basis of its profitability. This does not require that each farmer be motivated exclusively by profit maximization. Nor does it require perfect knowledge on the part of the entrepreneur. It simply means that on the average, those managers who make the most profitable decisions from among *available* choices will survive, expand, and replace those who do not.

Since technical efficiency is usually profitable, it seems to follow that the decision-making processes of many profitseekers lead to the most efficient technology. Current practices, having passed the test of competition, therefore might seem to be about as efficient as possible. The criteria of profitability might also be applied in a looser way to the behavior of public research institutions and researchers. Research proposals are "sold" to funding agencies; universities market their performance to state legislatures; and the employment of researchers and resource allocations between departments is decided on the basis of some implicit standard of productivity and worth.

However, the relations between the behavior of parts of a system and the efficiency of the total system is less obvious. Several features of the current agricultural system as it relates to pest control should be noted:

1. Adoption in pest control is a local process; that is, choice is made from among available options.
2. The available options are determined by the resources and knowledge of the farmer; the alternatives made available by the machinery, chemical, and seed companies; the regulatory environment; and the research and information generated by public institutions. In the short run, it is clear that commercial profit-related decisions made by farmers and suppliers of agricultural inputs are critical in the determination of pest control methods. For instance, chemical control methods are more easily converted into marketable commodities than are integrated control schemes, especially for the chemical companies that dominate this field. This may not always be so, but it is now.
3. A technical innovation typically is developed for insertion into the current agricultural practices of those who might use the product. Therefore, there is more effort to develop hybrid corn for the Corn Belt than for West Virginia, machines are designed more for large expanses of flat land than for small hillsides, and so on.
4. Technical change contains self-reinforcing feedbacks. The replacement of hand labor by machinery reduces job opportunities, causes emigration from farm areas, raises the cost of labor, and makes mechanization more necessary. Machines designed for pure crop stands ultimately make pure stands necessary. Experiment stations tend to emphasize work on the crops actually grown in the region much more than on potential crops. Therefore, regional specialization is reinforced. Profitable and

efficient chemical pest control discourages the development of other practices, and this makes chemical methods seem more necessary.

5. Technical and economic adjustments by farmers and other businesses typically are short-range in nature. Because of economic uncertainty and other unknowns, the future is heavily discounted in current decision making. Similarly, research administrators with an applied agricultural mission tend to seek solutions to current problems. This often leads them to caution, avoidance of risk, and insistence on short-term results. Long-range, basic research often receives lower priority.

For these reasons and others, some fundamental notions of genetics and ecology have not adequately entered into traditional pest control research. Much of the research in this area is dominated by large-scale trial-and-error screening of both plant varieties and control chemicals. However, some new directions in pest control and management are being examined. Some of these ideas and concepts may have application in the corn and soybean sector.

Future Directions in Weed Control

Although chemical herbicides dominate the corn/soybean weed control scene, some other modes of control are being studied. In the area of biological control, preliminary attempts are being made to control Canada thistle, the worst broadleaf perennial weed in corn and soybeans, by means of the Italian thistle beetle, which thrives on the weed but does not damage other crops. Success hinges on the ability of this insect to survive and increase in the Corn Belt and upon the lack of undesirable side effects.

Use of electromagnetic radiation (microwaves) for weed control in crops is under investigation in Texas. Currently available equipment is effective but very cumbersome. The radiation output is too low and energy requirements too high to allow economic usage on the extensive acreages of corn and soybeans in the Corn Belt at the current state of development. Further development of this kind of control will hinge upon technical progress in electronics rather than biological developments.

Specialized new spraying equipment may allow treatment of certain weeds in soybeans with greatly reduced quantities of herbicides coming in contact with soybeans or being released into the environment. These sprayers direct a stream of herbicide liquid at weeds extending above the soybeans. Liquid not remaining on the weed is caught by the equipment and reused. This type of equipment is not yet developed sufficiently for extensive use in commercial areas.

The following are some very new principles in weed control that may form the basis for future applied research and development.

1. The breeding of varieties that are more competitive with weeds (e.g., taller) without losing too much in yield or adding too much vulnerability to wind damage.
2. The use of mechanical barriers on the soil surface (e.g., plastic strips as used on some horticultural crops).
3. The development of weed seed dormancy breakers or germination stimulators (e.g., the use of ethylene on witchweed as germination stimulator).
4. Interplanting of crops to control weed competition (e.g., soybeans seeded with winter wheat).
5. Isolation of biotic toxins or pathogens for specific problem weeds. For example, velvetleaf and black nightshade are inhibited or killed if heavy populations are grown on the same area for several years. Accumulation of toxins or pathogens in the soil are possibilities. This phenomenon is called "allelopathy." For example, cucumber strains have been found that produce chemicals that stunt weed growth.
6. The application of plant pathogen spores to weeds (e.g., the control of northern jointvetch in rice by means of plant disease).
7. The use of laser beams as a highly controlled heat source to kill weeds selectively within crop rows.

Future Developments in Insect Control

An increasing emphasis in applied entomology is focused in the term "pest management." This approach emphasizes the optimal use of all available methods for pest suppression. For success, these methods must be based on sound biological and ecological principles and should have minimal effects on the environment. This represents an approach to optimal use of all available methods. They may be employed singly, in multiple sequence, or in various combinations in order to reduce net loss from pests. Pest management has two basic objectives: (1) minimize loss incurred due to pest attack, and (2) minimize the impact in the environment due to the pest suppression methods used. In most cases, these management programs have resulted in a reduction of the quantity of pesticides used. Currently there is a six-state (Iowa, Illinois, Indiana, Missouri, Ohio, Nebraska) pilot pest management action program for corn funded by USDA and the Extension Service. Primary emphasis is on insects with lesser emphasis on pathogens and weeds. One net effect of this program has been a more judicious use of insecticides, which has led to a reduction in insecticide use.

Chemical pesticides probably will continue to be the primary plant protection tool in insect management programs for the immediate future. Therefore, it is important to continue improvements in several areas, including the proper targeting of pesticides in the application process, definition and identification of economic thresholds, determination of effective minimal application rates, selectivity and degradation of pesticides, and similar areas. Pesticide application today is often not very specifically directed. This is because we lack knowledge about the biology and behavior of insects or because equipment is not available with which to direct applications to restricted areas. Thus a considerable quantity of insecticide is wasted or lost, because it is spread over a wider area than the effective target site. Consequently, pesticide efficiency could be enhanced through research directed toward more specific application. The targeting would be improved if we had an improved knowledge of the behavior of specific insects. An example of a present success is in the treatment of specific resting habitats for the control of some mosquito species. The development of better equipment for more specific targeting of insecticides requires the use of advanced engineering methods.

Further research in pesticides should be directed toward: (1) identification and development of more selective compounds, (2) timing of application with relation to parasitosis and predators, (3) minimum dosage rates for effective control of target pests, and (4) pesticide interactions. Present pesticides are broad spectrum chemicals that have an effect on pests, as well as on beneficial species. Incentives or some other management schemes must be identified in order to encourage the development and marketing of more selective pesticides.

The study and development of plant resistance to pests has been very productive in proportion to the time and resources devoted to it. Plant resistance is an ideal method to control an insect species if yield and other desirable characteristics can be maintained. This is primarily because it does not have secondary environmental effects and it does not require specific action by farmers to achieve control during the growing season. But as the control objectives of a plant breeding program increase to encompass insect resistance, problems with maintaining yield and other desirable characteristics are likely to increase.

Currently, sources of resistance have been identified for the following crop and insect combinations: corn -- European corn borer, corn leaf aphid, and corn rootworm; soybeans -- Mexican bean beetle and green cloverworm. Varieties having resistance to the European corn borer are not available to producers. Other sources of resistance or tolerance to insects have not been incorporated into commercial varieties. Laboratories or centers could be developed to evaluate the susceptibility of new varieties to pests in order to guard against the release of highly susceptible varieties.

The potential of novel chemicals such as pheromones (attractants), mating inhibitors, and juvenile hormones (maturity arresters) should be explored. Juvenile hormones have exhibited some effectiveness against some corn and soybean insects. However, their practical usefulness has not yet been demonstrated since many corn/soybean pests are injurious as larvae. Pheromones have not been investigated extensively in the insects that attack corn and soybeans. A pheromone has been identified for the European corn borer. Insects have evolved very complex reproductive processes that involve intricate chemical signals and behavioral responses. Systems might be developed that would interfere with such processes. Pheromones probably will find primary use in traps for monitoring pest populations. There is a wide range of chemicals that have a critical role in important life processes. These processes might be interrupted or confused in order to reduce population development.

Pathogens can serve as a major control agent. The use of pathogens, including bacteria, fungus, and viruses as control agents in the traditional sense of insect control, holds great potential; and a large number of parasites and predators have been identified from various insect species. *Bacillus thurigiensis* does control certain Lepidopterous larvae, such as the green cloverworm. But it is the only organism currently registered for such use. Programs are needed that will (1) enhance the natural development of indigenous pathogens and (2) encourage development of technology to propagate biological controls.

Field application tests have been conducted with several viruses. Currently there are two primary areas that need to be developed so that viruses can be used in control applications.

First, production of large quantities is a primary limiting factor. Second, the registration of a virus for application is scrutinized in considerable detail by government and industry in order to determine the broad aspects of safety and to establish efficacy standards.

Pathogens are known to play a significant role in nature, and it has been postulated that the sporadic nature of some pests may be attributed to the "failure" of natural biological controls, including pathogens, parasites, and predators. Both of the latter have been shown to play a significant role in natural populations.

At present, schemes have not been devised to produce, release, and manage parasite or predator populations so as to have a significant effect on a pest population in corn and soybeans. A parasite and predator release and management program has been attempted in other grain crops but has not been successful. It may be desirable to develop management techniques to raise nuclei or islands of pest species that are infected with a disease organism or parasite in the field. Similarly, predators also might be raised in the field. It may also be possible to maintain the same controlling organisms in nonpest species in the field.

Culture and management practices have an impact on the pest problem. The western and northern corn rootworm likely could be controlled without chemicals, if continuous corn were not grown over wide acreages for several years without interruption. Adults tend to stay in cornfields to feed and deposit eggs. The eggs overwinter and hatch the following spring. The larvae are relatively host-specific, and only a very limited number survive on alternate hosts. The increase in soybean acres is important; because, if soybeans and corn are used in an annual rotation in critical areas, effective control can be achieved. There are other management and cultural practices that affect pest problems though none are as dramatic as the rootworm example. Stalk destruction substantially reduces European corn borer population. Egg laying of some cutworm species and rootworms is reduced in cleanly tilled fields. These are not new ideas, but would represent "new" practices if introduced in reduced-tillage, continuous-corn areas.

Another approach to insect control would involve the use of mixed strategies in a single field. One potential plan might involve the use of a tolerant variety when slower-acting pathogens are present or minimal doses of insecticides that have a minimal effect on natural control agents. A combination of strategies may be advantageous but is likely to require a sophisticated assessment capability and good management. Yet an increase in the available lead time for taking action against a threatening population may make it possible to use mixed strategies in a population suppression effort.

Both the western and northern corn rootworms probably could be reduced to no-pest status by using a strict rotation. The decision whether or not to include individual fields in a specific rotation scheme could be based on the measured probability of an insect problem in those fields. Some extension education programs now are presenting crop rotation as one alternative for achieving insect control.

Another approach might involve the development of an autocidal genetic character in a pest population to reduce its ability to survive in its natural habitat. A change might be affected in the behavior or physiology of a pest that would reduce its survival potential. Another innovation might involve specific planting regimes, trap cropping, or other modifications of existing crop patterns. Pests might be lured to a particular crop or side; thus concentrated they could be exterminated while in a relatively confined area.

Most of the primary soybean and corn insect pests have a diapausing or overwintering stage. There might be unique features of this phenomenon that could be identified and exploited. Early or delayed triggering of diapausing could be a powerful control mechanism.

A further step that might be considered is legislation or regulation to provide for mandatory specific crop rotation by farmers. Such legislation would represent a major new thrust in pest control in corn and soybeans. Such measures no doubt would be highly controversial, unless insect problems become extremely severe.

Generally, these approaches will not result in a patentable item or marketable products on a large scale. Therefore, funding for development and deployment must originate primarily in the public sector. Research effort will also be needed in the implementation and acceptance of the nontraditional pest suppression techniques by the grower.

Currently, there are some ongoing research programs that could lead to new approaches. However, these programs are all lagging due to low funding. In general, they are designed to develop predictive capability with regard to both the location and magnitude of insect populations. The tools of systems analysis and simulation modeling are being utilized to some extent. The development of predictive capability is the key to most new methods of insect control.

There is a need for an increased knowledge base in order to develop the technology for integrated pest management systems. Knowledge, applicable to a problem's solution, must be implemented in an effective and efficient manner if its value is to be realized by the grower and the general public. The introduction of pest management practices at the grower level is generally difficult as compared with the introduction of a new product for sale. Therefore, there is also a need for research, innovation and increased emphasis on research concerned with the effective dissemination of management principles and techniques. The key to effective and ecologically sound pest management is, in a major way, dependent upon the transfer of knowledge and the implementation of technology. Thus, specific attention needs to be given both to strengthening the fabric of existing, successful institutions that disseminate useful knowledge as well as the fostering of new institutions that will disseminate knowledge and technology in new ways. It is important that there be a continuum between research activity and knowledge transfer.

Future Directions in Plant Disease Control

New directions in plant disease control can be grouped into (1) management practices, (2) protectants, and (3) plant resistance.

New management practices can be aimed toward greater destruction of overwintering crop refuse. This could include, for example, burning or early incorporation of crop residue into the soil soon after crop harvest. Another practice might be a more systematic rotation of crops or of different varieties of the same crop. This would be done such that the planting of a crop variety known to be susceptible to a disease might be avoided in a field where a high frequency of overwintering of that disease-producing organism exists. Several corn viruses or viruslike agents overwinter in the perennial plant Johnson grass. Shattercane is a self-seeded host for the corn and sorghum downy mildew fungus. Shattercane or sorghum seems necessary for the survival of this fungus in the Corn Belt. The suppression of these plants in part or all of the sector would substantially reduce or perhaps eliminate the threat of corn viruses and downy mildew. Other weeds are hosts of the soybean cyst nematode. Their control would aid in the control of this pest. These management practices are similar to those mentioned earlier in connection with insect control.

Most, if not all, disease control practices are compatible with those for insect and weed control. Insects such as the corn flea beetle, corn rootworm, aphid, leafhopper, corn borer, and others serve as vectors of corn and soybean disease agents. Insect feeding injuries on plants also provide favorable sites for infection by disease-producing agents. Hence, the control of these kinds of insects contributes to plant disease control. Some weeds, as mentioned previously, serve as alternate hosts to corn and soybean disease-producing agents and, hence, weed control also contributes to disease control. There are few instances where the absence of an insect or weed makes it more difficult to control disease on corn or soybeans.

Protectants are not now used extensively in the control of corn or soybean diseases. Some fungicides have been approved for usage, but many compounds have not been tested. Proper rates and schedules have not been developed. After the crop has been harvested, spraying the crop residue with control chemicals and other compounds can reduce the overwintering population of plant pathogens. This practice could control some plant diseases, but might add carryover contamination problems to the environment.

New approaches in the usage of host resistance are possible. Legal restrictions on the usage of specific genes and cytoplasms for resistance to certain areas could be imposed. For example, *Helminthosporium maydis*, the cause of southern leaf blight in corn, is limited in its distribution mostly to the southern and eastern portions of the United States. The organism is not common in the Corn Belt. New races of this pathogen are likely to appear in areas where *H. maydis* is endemic. Such new races can increase in prevalence when the crop is susceptible and spread into new areas. Hence, a resistant form of cytoplasm would more likely remain effective longer in the Corn Belt if the same cytoplasm were not to be used in the area where *H. maydis* is endemic.

Several genes and cytoplasms are frequently available for resistance to a given disease. Certain combinations are known to scientists that are almost sure to impart resistance. By some sort of registration and licensing system, only crop varieties having these combinations could be permitted for release. To prevent excessive uniformity, only a certain percentage of the corn crop or soybean crop might be permitted that had the same genes and cytoplasms for resistance. On the farm, growers would be required to plant a minimum of two soybean varieties or corn hybrids. Each variety or hybrid would be required to possess a different breeding background. To meet this objective, plant breeding programs would be required to maintain and improve different sets of germ plasm pools of these crops. As with mandatory rotation schemes, these kinds of legal restrictions on growers' decisions would be a new direction in pest control methods.

Plant pathology and genetic-testing laboratories might be established to evaluate all potential new varieties and hybrids for reaction to all known diseases and variants. They would also determine in each variety the genes and cytoplasms for resistance present and establish minimum requirements for levels of resistance. They would be responsible for establishing and enforcing license requirements for crop varieties or hybrids. Since new disease problems continue to arise through changes in cultural systems practiced by farmers or through changes in the agents that cause plant disease, these laboratories also would be responsible for monitoring the crop and its pathogens. Plant breeders and seedsmen then could be alerted to needed changes in their breeding and seed production programs. These laboratories could provide a better evaluation of germ plasm collections and establish a "bank" of resistant genes and cytoplasms from which breeders could draw.

Very new and novel methods of plant disease control could be aimed at the eradication of the disease-producing agent or in some way changing the genetics or physiology of the pest so that it is less able to survive in nature. Suppression schemes could include the passage of equipment over the soil and crop debris; which, by means of ultrasonic or radiation treatment, would result in the death of all causal agents of plant disease. This objective also might be accomplished by chemical fumigants or eradicants. Some chemicals such as 4-N-butyl-1,2,4-triazole are systemic in the wheat plant and, when applied as a single treatment to seeds or young plants, provide protection against wheat leaf rust. Although these compounds are expensive and highly selective, they might prove useful against the causal agents of corn and soybean diseases.

Causal agents of plant disease have evolved efficient methods of reproduction and survival. Through the discovery and application of growth or reproductive hormones, they might (1) be induced to form nonrepeating spore stages more rapidly than normal during their life cycle; (2) be induced to have a lower reproductive rate; (3) be made more sensitive to low temperature and, therefore, survive poorly through the winter; or (4) fail to produce structures that are normally produced and that are resistant to unfavorable environmental conditions. Genetic or chromosomal abnormalities might be induced in certain isolates of a pathogen in the laboratory. When released into the pathogen population in nature, some of these abnormalities might upset the genetic balance of the pathogen population so that fitness is reduced.

Fungi, bacteria, and nematodes that cause corn and soybean diseases are also naturally parasitized by other microorganisms and viruses. Therefore, it is possible that mycroparasitism could be developed as another biological control in addition to host resistance as a means of disease control. The mycroparasites would need to be identified, produced in the laboratory, and released into the pathogen population in nature.

Some microorganisms are antagonistic to other microorganisms. The same is true for different strains of the same organism. Mass rearing and transfer of antagonists from the laboratory or from a suppressive soil to a conducive environment might reduce the disease-producing ability of some causal agents of corn and soybean diseases.

UNEXPLORED BUT POTENTIALLY FEASIBLE FUTURE STRATEGIES EMPHASIZING BIOLOGICAL METHODS OF CONTROL

The general outline of a future pest control strategy is just beginning to appear. It involves the development of a large repertoire of separate techniques, including biological methods of control rather than a single magic "bullet." Each of these procedures may have multiple effects on the agricultural system -- some beneficial and some harmful. For instance, a rotation of corn with soybeans can help control rootworms of corn but may prevent the use of certain herbicides on corn. The addition of small grains to the rotation may enhance the control of diseases but introduce new weed problems. Chemical pesticides can control some insects until they evolve resistance, but they also may poison other species.

With a good general knowledge of an agricultural system, it is relatively easy to point out possible good and bad effects of a technique. But the appropriate weighting of these effects and their integration into a management strategy is not a trivial problem. The study of how the parts of the system interact requires techniques of its own, a semiquantitative or quantitative systems analysis.

Strategy Components

The components of the strategy may be classified according to time-scale of operation, who makes the decisions, the problems they are designed to meet, the knowledge needed for their application, and the natural phenomena they depend on.

Time Scales

A more or less permanent pattern of land use has the objectives of keeping pest populations at generally low levels, making it difficult for outbreaks to spread or for new pests to invade the community, and maintaining the populations of predators and parasites. This pattern should be mostly self-operating, without requiring the farmers to carry out repetitive operations or introduce external materials. However, a small amount of maintenance of the system is possible.

Then, at the start of each season, decisions must be made based on weather predictions, anticipated pest problems, and economic need. The decisions include choices of varieties, density of planting, soil treatment with pesticides, and choice of intercrop. Emergency measures may need to be taken during the growing season when the crop is threatened. These include combinations of chemical pesticides, insect disease organisms, traps and attractants, introduction of large numbers of predators, and quarantine procedures to isolate an outbreak.

Size of Unit

The size of the effective unit for pest control may be smaller than, equivalent to, or much greater than the individual farm. In the first case, the decisions will continue to be made by the production unit. But decisions on a larger scale also will be required. They could include:

1. A regional land-use scheme to reduce monoculture vulnerability. Since this may require diversion of land to unprofitable uses, some policy to redistribute income in compensation may be necessary.
2. The release of introduced predators, parasites, or disease.
3. The carrying out of quarantine crop destruction in an emergency.
4. Coordination of the rotation of pesticides to try to prevent the evolution of resistance.
5. Provision of refuges for bats, birds, and other predators.

It is possible to visualize pest control districts, analogous to mosquito abatement or soil conservation districts, evolving under such a long-run strategy.

Mixed Land Use

At present, the Corn Belt is overwhelmingly dominated by corn and soybeans. This means that if there is an outbreak of a disease or insect pest, it is able to spread over a virtually continuous habitat. This has the effect of reducing the diversity of organisms, including those that may play a role in the control of pests. It is recognized that at least some pest problems are accentuated by monoculture and that the trend to more chemical pesticide use is partly a result of the lack of crop diversity.

The diversion of some land from the corn/soybean system either to other crops or special noncrop uses can make the following contributions to pest control:

1. Provide refuges for organisms that prey upon pests, including nesting sites for birds and ants.
2. Offer nectar sources for the adult parasitic ichneumonid and chalcid wasps.
3. Provide host plants for a wide variety of insects (including even a small pest population) to maintain parasite populations at levels capable of responding to outbreaks. It would also provide food in the off-season for spiders, carabids, empids, and other predatory invertebrates.
4. Provide gaps in the spacial distribution of a crop. This turns cropland into islands that can impede the spread of pests during outbreaks and delay the reinvasion of fields after rotation. For those species that can only spread slowly, local eradication with delayed

reinvasion may eliminate the pest or cause its population to peak too late for damage.

The extent of the non-corn/soybean patches is constrained by both economics and biology. If land diversion could save 10 percent of crop from destruction by pests, the break-even point might be greater than 10 percent of the land; since diverted land could produce some income and there would be a small saving in pesticide practices. Price relationships and responses also would have to be considered. The individual patch size needed varies according to the circumstances.

Bats, which may be useful against moths, can fly 20 miles in a night's feeding. Therefore, a pesticide-free refuge every 5 miles might be sufficient to maintain them. For birds, patches of a quarter acre free from toxic pesticides are about the minimum. If harvester ants prove useful in pest control, a noncultivated enclave of several square meters every 50-100 meters would provide secure nests. Nectar and other food sources for invertebrates could occur as an occasional row or small patch.

The effective isolation distance between fields of the same crop depends on the pest of concern. For nematodes and some soil insects, a band of several meters may be effective; while for the most mobile rusts, isolation may be totally useless.

Intercropping and Rotation

If economically feasible, crops other than the main crop may be interplanted in the same fields for several good biological reasons. First, an early, rapidly growing plant or group of plants may be able to suppress the growth of early weeds. Second, an especially attractive host plant may concentrate pest insects by diverting them from the crop and making them more vulnerable to predators and parasites. Third, the feeding and host location behavior of insects depends mostly on olfactory clues that can be confounded by the presence of other plants giving off contradictory signals. Fourth, other plants can modify the very local microclimate, including the soil.

Crop rotation affects the dynamics of populations of pests directly and through their enemies. Pests that are specialized to a single host and have low mobility, such as rootworms, may be controlled by rotation. Yet, specialized parasites may lag a rotation behind their hosts in population growth, permitting outbreaks of the more mobile pests.

Rotations and mixed plantings also can be carried out with different varieties of the same crop. The use of a mixture of strains with resistance to a pathogen based on different genotypes is both an insurance against the sudden spread of new pathogen strains and retards the adaptive evolution of the pest. A system of registration and licensing of varieties could be used to promote resistance and heterogeneity in the crop for the pathogen.

On the other hand, plants that are obviously different from man's viewpoint may be effectively the same to a pathogen. Johnson grass permits the overwintering of several corn viruses or viruslike agents; shattercane is a host for corn and sorghum downy mildew fungus. Such plants in a mixed scheme might defeat the purpose of the mixture or rotation.

The Invertebrate Community

The invertebrate community of a cultivated field is maintained directly or indirectly by the crop itself, by intercropped plants, and by the primary production coming from noncrop enclaves and borders. The major food source must be the crop residues. The herbivores that feed on these residues, such as insect larvae, mites, and collembola, prepare them for further decomposition by the microorganisms and alter their physical structure, therefore, their refuge value for overwintering insects. Together with the herbivores they maintain the populations of generalized predators and omnivores, which do most of the feeding on pest species. These include spiders, carabid beetles, predatory mites, ants, and some wasps.

The generalized predators are the first line of biological control, since they can be present in reasonably large numbers without the target pest species. Cultural techniques could be adapted to maintain these populations. Since some of the predatory beetles have herbivorous larvae, host plants for them would need to be provided. Otherwise, the predatory population can be maintained by restricting pesticide use both in quantity and in time of application to avoid the vulnerable stages of their life cycles and by providing patches of diverse vegetation that will give them adequate prey.

The specialized parasites are either wasps, flies, or mermethid nematodes. Since they are often restricted to a single host, they cannot maintain large populations when their host is rare. On the other hand, they respond quickly to the growth in the population of their hosts.

A specialized parasite may control the equilibrium level of a pest, even if it is responsible for only a small part of the normal mortality. Anything that increases the standing parasite level (better nectar sources, an available alternate host, more hiding places) will reduce the average pest population and allow more rapid response to major outbreaks. However, the short-term fluctuations in pest populations are more influenced by the generalized rather than the specialized predators.

At our present level of knowledge, it is not possible to detail the role of the insect community in control of specific pests. There is no general survey of insect fauna of cornfields available, except for a single dissertation from the University of Minnesota. Nor has the feeding range of the generalized predators been detailed.

However, some characteristics of these groups are worth noting.

1. There is quite a large number of species that are of potential use. For example, in Latvia there have been found more than 1,200 species of ichneumons. Of these, about one-fourth parasitize important pests. In corn in Ohio, 60 species of Hymenoptera, 145 beetles, and 32 spiders have been identified.
2. The parasitic groups are generally less specialized in their plant requirements than in their insect host requirements. In one study, 79 species were attracted to a 3.5 square meter plot of parsley in 12 hours, and 53 species came to buckwheat plots.
3. Predators may adapt to new pests fairly rapidly. Predator and parasite species are heterogeneous with local races differing in demographic parameters, environmental responses, and feeding behavior. Therefore, artificial selection may be carried out to provide for the availability of control organisms.
4. Each parasite or predator species has its own seasonal pattern and sensitivity to weather conditions. This makes their effectiveness highly variable. But a system of several parasites may give better control than a single parasite.
5. The effectiveness of a parasite is partly limited by the resistance of the host. For instance, hosts may encapsulate the eggs of a parasite. This host resistance can be undermined by bacterial infection and possibly by chemical means.
6. Some data suggest that a single predator may eat several hundred to several thousand pest insects in its lifetime.

7. The fact that several species of parasites are apparently specialized on the same pest suggests that they coexist by using different microhabitats or seasons. Their effectiveness might be enhanced by providing microhabitat refuges.

Soil Microbial Community

The soil flora is relevant through nitrogen fixation, possible detoxification of the atmosphere and soil, decomposition of residues, insect pathogens, and plant diseases. Microorganisms compete directly for nutrients, secrete nutrients that may stimulate other microorganisms, and inhibit each other's growth chemically. The pest control objectives of manipulating the soil flora are to (1) suppress the growth of and compete with pathogens of crops, (2) promote survival of the pathogens of insect pests, and (3) establish populations of hyphomycetes fungi, which trap nematodes. The means of manipulation are inoculation of specific organisms, addition of special nutrients, planting of vegetation for its residue, and general culture practices.

Soil insects such as rootworms and wireworms are relatively less accessible to some parasites and surface predators than surface insects. Therefore, microbial control organisms may be effective for control of these pests.

Vertebrate Predators

Among the vertebrates, bats and birds consume large quantities of insects. The corn borer adult is a moth that flies to mate and find new sites. The flights occur in the evening and night. Bats may be effective predators during this period. Insectivorous birds can catch moths on the wing and also may take insect adults or larvae on exposed plant surfaces.

Both birds and bats can fly long distances to forage. As mentioned, refuges every few miles might be sufficient to maintain effective populations. Secondary problems with large colonies of bats and/or birds would need to be evaluated. These might include increased risk of rabies via the bats and increased crop damage by birds.

Other Factors

Autoecology of Pests

In principle, any stage of the life cycle of a pest may be interrupted, delayed, or diverted. However, not all stages in the life cycle are equally vulnerable, and a given amount of mortality is not equally effective in curbing population growth. Where density-dependent effects are important in major outbreaks, mortality at stages prior to these effects have little impact. If predators and parasites help control a pest, a new source of pest mortality at a stage after the parasites and predators have acted will compete less with them and act as a supplement rather than competitor.

Population growth is usually treated by considering each age class as a distinct variable. However, the changes that occur when an insect develops makes developmental stage rather than chronological age more useful in considering controls. For example, if dwarf plants force corn borer larvae to remain closer to the ground or if some aspect of the corn genotype promotes their downward movement within the plant, then at least two factors must be considered. Since the average temperature is higher nearer the soil surface, larvae development is accelerated; but episodes of very high temperature will increase mortality among some larvae.

Because of the exponential nature of population growth, a seemingly small change in the rate of growth can have a marked effect on the population. For instance, suppose that a population of aphids increases 10,000-fold in the course of the summer. Then e^{rt} is 10,000, where t is the time elapsed and r the intrinsic rate of increase. If a combination of control measures reduces r by half, the population will only increase by 100-fold. This may be brought about by a mixed strategy of agents slowing development, increasing mortality, and reducing fertility.

Egg mortality can be increased by predation. Larval mortality is sensitive to disease, parasitism, predation, and chemical pesticides as well as moisture and temperature. In the corn borer, larval mortality is the most variable factor of mortality from year to year and therefore probably most amenable to increase. The development rates of insects are sensitive to temperature, each stage requiring the accumulation of a certain number of "degree days" above 50 F. Since midsummer temperatures in the Corn Belt are often in the 80s, degree days accumulate at the rate of about 30 per day. Cultural practices and growth habits of the crop can alter the temperature of the insects in the field by perhaps 2-3 F, slowing development up to 10 percent. Since the typical maximum daily midsummer temperature is above the optimum for corn growth, there is no direct physiological loss by so doing. Whether a 10 percent reduction in development rate is worthwhile or not depends on the pest in question.

Larval mortality can be increased if the search for food is made more difficult or if penetration of the host plant is delayed, since this increases the exposure to predation and parasites. The host location process is largely chemical. It can be interfered with by intercropping, developing specific chemicals that confound the olfactory system, attracting insects to specially bred host plants, or changing the host chemical composition.

Overwintering mortality is probably most amenable to cultural practices, especially the treatment of stubble and crop refuse, as has been discussed earlier.

The fertility and fecundity of insects can be reduced by introduction of sterile males or translocations into the population, pheromonal interference with courtship, or increased predation or threat of predation during mating flights (e.g., for noctuids, the bat sonar frequency causes them to drop to the ground). The location of suitable egg laying sites can also be sabotaged.

Finally, we note that development may be disrupted by providing false environmental information (for instance artificial light to prevent diapause) or the wrong response to that information (by introducing genes from other geographic regions).

Synthetic Chemicals

Chemical substances that occur naturally may be applied to agricultural systems, either by cultivating their source (intercropping, inoculating with microorganisms) or by mechanical means after extracting, identifying, and synthesizing the molecule. The first course of action has the advantage of establishing a self-sustaining, automatically operating system in which the active substances can be released continuously. But this requires diversion of land or nutrients. Their application as chemicals permits greater control over their timing, concentration, and combination with other substances. Modifications of the molecular structure then enhance effectiveness. For substances that do not occur in nature, the option does not exist. Otherwise, a mixture of choices should be kept available.

Chemical methods of control are not limited to lethal pesticides. Specific chemical substances also may be used to (1) weaken insects, increasing their vulnerability to disease and other stress; (2) attract them to traps; (3) repel them from crops; (4) divert their development (hormones); (5) supplement the nutrition or stimulate the growth of control organisms; and (6) promote germination of disease spores at a time not suitable for infection.

Artificial Selection

Genetics is now used almost exclusively on the crop plants themselves -- breeding for yield, chemical composition, and disease resistance. Plant breeding is a difficult process in which desirable genes are unique occurrences that must be saved and propagated. Therefore, progress in breeding almost inevitably is accompanied by the loss of genetic variability and the creation of uniform genotypes. At the same time, the loss of variability makes further breeding more difficult, and each additional criterion for selection compounds the difficulty.

Genetic heterogeneity is generated spontaneously by mutation and natural selection in the field. But since almost all corn and much of the soybean seed are now purchased from commercial seed producers, this source of adaptive variation usually does not reenter the gene pool. The sampling of local populations and their planting and reseeding may enhance the available genetic material, especially after major pest outbreaks.

Three kinds of genetic heterogeneity may be useful:

1. A geographic mosaic of varieties with different vulnerabilities can retard the spread of pest outbreaks.
2. Varieties can be kept in reserve to rotate regularly or introduce in an emergency.
3. A mixture of genotypes in the same stand may contribute to control of microclimate, retard the spread of slow-dispersing pests, or concentrate the pests on particular plants where their predators and parasites may be more effective. But in order for mixtures of genotypes to yield well, they may have to be selected for performance in mixture.

However, artificial selection need not be limited to crops. Potential parasites of pests can be selected to change hosts or to tolerate new microhabitats. Plants can be selected for intercropping with corn or soybeans or for their effectiveness in attracting pests, suppressing weeds, promoting predator growth, and maintaining the microflora. Microorganisms can be selected as pathogens of pests. Genes may be introduced into pest populations that, while functioning successfully during normal times or certain seasons, will prove to be lethal either when winter sets in (perhaps by disrupting diapause or dormancy) or in some special environment that we can impose (for instance, it may confer susceptibility to a pathogen or pesticide). Systems of selected chromosomal translocations can reduce fecundity of pests.

Expecting the Unexpected

New pest problems have arisen from time to time with unfortunate impact on the agriculture of particular regions. Agricultural research has responded rapidly; and, within a few years, often has been able to control the problem.

These problems are often treated as "acts of God," intrinsically unpredictable events to which we respond as best we can after the fact. But as knowledge improves and as we increase our capacity to anticipate disasters, the failure to look for trouble in advance becomes irresponsibility.

New pest problems may arise in several ways, each of which requires different methods of anticipation, for example, the spilling of a present pest across its boundary to invade new regions. This happened with the southern corn leaf blight and is happening with the western corn rootworm. Such a change in distribution may come about due to a change in the pest itself (the acquisition of insecticide resistance in the rootworm), a change in the general environment, or in the vulnerability of the crop (in the case of the corn blight, the widespread use of the male sterile cytoplasmic factor). Therefore, the first step in anticipation is the study of the factors maintaining the present boundary of a pest, the rate of spread once the limiting conditions are modified, and the ease with which the pest itself may change.

Long-distance introduction of a pest from other regions of the world may occur. Many of the present major pests have been introduced in recent times into the United States from other regions. In spite of the efforts of quarantine agencies, the increase in world commerce makes such introductions inevitable. A three-tiered defense system is needed. First is the improvement of quarantine practices. Second is the establishment of procedures to attempt total eradication of a new pest very soon after its first introduction. Third is a reserve of chemicals and genetic material to be released in case of exotic infestation of, for example, soybean rust in North America.

A herbivore or disease already in a region may change host and become a crop pest. The change of host must have occurred many times since the beginning of agriculture, although it is not often observed as it happens. A general understanding of host specificity, the plasticity of host range in different taxonomic groups, the behavior and biochemical mechanisms of host location and acceptance, and the experimental investigation of the ecologies and genetics of host change should make it possible to pick out candidates for close surveillance.

Drastic changes in production in a region due to either climatic or economic shifts can impose a whole spectrum of new pest problems. For instance, if several years of drought caused a marked shift from corn and soybeans to small grains, what pests would invade the region? We should know.

RESEARCH AND POLICY PERSPECTIVES

The productivity of U.S. agriculture has increased tremendously in the last half century. The use of a variety of pest management techniques, ranging from plant breeding to chemical pesticides, has been essential to this increased productivity. Looking to the future, it is clear that in man's continuing struggle against hunger and malnutrition, effective pest management will continue to be critically important. This is not to suggest, however, that current pest management approaches should automatically be extended into the future.

The role of research and public policy in the evolution of pest management will be a determining factor in its success or failure.

Research

As agricultural productivity has increased, a smaller proportion of our social effort has had to be used for current maintenance and a larger proportion has been available to prepare for the future through education and research. This trend is likely to continue and to be reinforced by the desire to replace existing technologies with others that minimize external effects of which we are only now becoming aware.

But an increase in the amount of research is no guarantee that it will be effective. While members of the study team were not in full agreement as to the extent of the gap between fundamental and applied research in agriculture or in their evaluation of current efforts, they did agree on the necessity of a closer integration of research with different time horizons, probabilities of success, and scope.

Recommendations about needed research are usually made in terms of appeals to government agencies for the funding of new programs or increased support to existing ones. Such proposals may promote the illusion that the solutions to problems are mostly financial appropriations. Although it is certainly true that most agricultural research programs feel the pressure of limited resources, we emphasize also that new directions require changes of outlook in scientific and administrative communities and that a program for change is at least partly an intellectual struggle. The suggestions that follow are aimed at reducing the intellectual barriers between applied and basic research.

1. Agricultural research must go beyond the land grant system, the USDA, and state departments of agriculture. The urban universities should be incorporated into a national effort.

2. This does not mean doing fundamental work in the urban centers and applied work in the existing system. Rather, interuniversity programs should be developed in which students and staff from both systems would work jointly on general problems. The dichotomy of fundamental and applied research can be broken down and replaced with a program of doing useful work in a fundamental way. For example, the monitoring of the boundaries of distribution of pests could be done in such a way as to examine the general problem of species' boundaries.

Doing applied research in a fundamental way means that there must be a set of nested projects with differing scope and immediacy but each contributing to the accumulation of knowledge fundamental to the problem under study.

3. Monographs should be prepared similar in scope to the genetic vulnerability study (USDA and National Association of State Universities and Land Grant Colleges 1973). They would review a general problem area in a way that will give practical workers a broader perspective while introducing nonagricultural scientists to the rich intellectual concept of scientific problems in agriculture.

4. The professional societies concerned with agricultural pest problems (agronomy, entomology, photopathology) should promote symposia at their meetings and in their journals in which long- and short-term pest problems are discussed in the context of general theoretical issues. The professional societies not concerned with agriculture (such as the American Society of Naturalists, or the Ecological Society of America) should hold sessions and publish material on the biology of agricultural systems, economically important organisms, and introduced species.

5. A general laboratory manual of economically important organisms, their cultivation, use for classroom exercises, and potential for basic research should be prepared to enable and encourage students to study and use them in research having nonagricultural goals.

6. A public or quasi-public research organization should establish an advanced projects division to promote projects with high risk but big potential in the pest control field of the agricultural sciences.

7. Some vehicle should be found for groups such as these study teams, which are mixtures of agricultural and nonagricultural scientists, to function on a long-term basis.

Public Policy and Public Action

As this report has suggested, a variety of pest management approaches are theoretically possible, each with its own benefits and costs. Many of these benefits and costs accrue to individuals and groups beyond the immediate producers and users of the pest control technologies. Some of these externalities, especially possible adverse ecological effects of pesticide chemicals, have stimulated considerable public debate in recent years. For example, the publication of *Silent Spring* by Rachel Carson stirred heated controversy. Although the heat has subsided, many of the basic concerns remain. Environmental groups, for example, have sprung up to defend the environment against possible adverse effects of chemicals and other perceived threats. Agricultural and industry spokesmen speak out on the importance of maintaining high levels of output and efficiency in agriculture. Various other interest groups seek legislation to achieve their particular goals. It seems likely that in the future the legislative and executive branches of state and federal governments increasingly will be faced with the necessity of making decisions that bear directly on pest management. The Federal

Insecticide, Fungicide and Rodenticide Act of 1947, The Federal Environmental Pesticide Control Act of 1972, and the activities of the Environmental Protection Agency are indicative of the kind of public concern that can be expected to continue into the future.

If future public action is to result in increased benefits (social, environmental, economic) and lower relative costs, it is essential that such activity be as enlightened as possible. It is important that research on alternative pest management approaches *and their implications* be expanded. Such research is needed if more effective strategies are to be developed. It is also needed to provide more adequate information for use in shaping legislation and regulation.

It was not the purpose of this report to develop all of the issues that might be considered by public leaders in developing legislation related to pest management. Nonetheless, some basic ideas on this did emerge from our deliberations, and we feel they should be considered by policymakers as they assess the relative merits of alternative pest management strategies. The following is a summary of these issues:

1. Expected impact on *output* of food.
    (a) Expected impact on output of crop for which the technology is intended.
    (b) Expected impact on output of other crops.
2. Expected impact on *prices* of food and differential impact of supplies and prices of various food items on population segments both within the United States and abroad.
3. Expected impact on *food quality and safety*.
4. Expected impact on *environment and ecological systems*.
5. Expected impact on *safety of persons* employed in agriculture and industry.
6. Expected *energy requirements* and impact on *energy supplies* not only on farms but also in production, processing, and distribution of agricultural inputs and output.
7. Expected impact on the *structure of agriculture* and related industries.
    (a) Expected impact on *farm size*.
    (b) Expected impact on *regional distribution* of agricultural production.
    (c) Expected impact on *competitive environment* for firms producing farm inputs and secondary effects on employment.

8. Expected impact on *rural people and institutions* through effects on employment, farm income, and social stability.

9. Estimated needs for developing the technology to a feasible level, and to obtain its adoption.

   (a) What resources are needed for research and development? Who will do it?

   (b) Are supporting services and/or new organizational forms needed for implementation?

Not all of the ideas in this list are considered in detail in the main report. Nor are they of equal importance. Their relative importance will, of course, vary as situations vary. However, enlightened public policy and action in the pest control field will have to face and deal with each of these issues.

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